

**The Integration of
Unmanned Aircraft Systems to
Increase Safety and Decrease Costs of
Transportation Projects and Related Tasks**

Final Report

Prepared by University of Vermont Rubenstein School of Environment & Natural Resources
for the New Hampshire Department of Transportation, in cooperation with the
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16. Abstract The use of Unmanned Aircraft Systems (UAS) has the potential to reduce costs and increase safety for transportation operations ranging from bridge inspections to construction monitoring. The overall objective of this project focused on evaluating UAS technology for a broad range of case studies relating to the specific needs of the New Hampshire Department of Transportation (NHDOT). Specifically, this project's objectives are to: 1. Determine the types of transportation projects for which UAS are best suited for. 2. Evaluate the capabilities and limitations, along with the costs and benefits, of using UAS technology for a variety of transportation projects. 3. Outline the policies, procedures, staffing, and information technology infrastructure required for NHDOT to fully implement UAS technology. 4. Develop NHDOT's UAS capabilities. Eight case studies were generated to address accident reconstruction, airport runway and airport inspection, bridge inspection, construction monitoring, dam/emergency management, traffic monitoring, rail mapping and bridge inspection, and rock slope inspection. These case studies served the purpose of evaluating the applicability of UAS for NHDOT, comparing UAS to existing methods, and analyzing barriers to UAS implementation.			
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TABLE OF CONTENTS

1.0 OVERVIEW.....	1
2.0 UAS AND TRANSPORTATION.....	1
3.0 UNMANNED AIRCRAFT SYSTEMS WORKFLOW AND PROCEDURES.....	3
3.1 PROCEDURES.....	3
3.2 CHECKLISTS.....	3
3.3 UAS OPERATIONS.....	4
4.0 CASE STUDIES.....	10
4.1 OVERVIEW.....	10
4.2 CASE STUDY: ACCIDENT.....	11
4.3 CASE STUDY: AIRPORT RUNWAY AND AIRSPACE INSPECTION.....	16
4.4 CASE STUDY: BRIDGE INSPECTION.....	20
4.5 CASE STUDY: CONSTRUCTION MONITORING.....	23
4.6 CASE STUDY: DAM / EMERGENCY MANAGEMENT.....	26
4.7 CASE STUDY: TRAFFIC MONITORING.....	31
4.8 CASE STUDY: RAIL & BRIDGE INSPECTION.....	34
4.9 CASE STUDY: ROCK SLOPE.....	38
5.0 CONCLUSIONS	41
5.1 OPPORTUNITIES.....	41
5.2 IMPLEMENTATION CONSIDERATIONS.....	41
5.3 RECOMMENDATIONS.....	48
REFERENCE CITED.....	52
DEFINITIONS.....	53

THE INTEGRATION OF UNMANNED AIRCRAFT SYSTEMS TO INCREASE SAFETY AND DECREASE COSTS OF TRANSPORTATION PROJECTS AND RELATED TASKS

CHAPTER 1: OVERVIEW

Unmanned Aircraft Systems (UAS) are a new capability that has the potential to reduce costs dramatically and increase safety for transportation operations ranging from bridge inspections to construction monitoring (Gheisari et al., 2015). Despite the considerable amount of existing research and case studies surrounding UAS, there appear to be few, if any, that have focused on analyzing the costs, benefits, and barriers associated with integrating UAS into a state department of transportation's operations. The overall objective of this project focused on evaluating UAS technology for a broad range of case studies relating to the specific needs of the New Hampshire Department of Transportation (NH DOT). Specifically, this project's objectives are to:

1. Determine the types of transportation projects for which UAS are best suited for.
2. Evaluate the capabilities and limitations, along with the costs and benefits, of using UAS technology for a variety of transportation projects.
3. Outline the policies, procedures, staffing, and information technology infrastructure required for NH DOT to fully implement UAS technology.
4. Develop NH DOT's UAS capabilities.

This project was a partnership between NH DOT and the University of Vermont's (UVM) UAS Team. UVM's UAS Team conducted flight operations and generated products for eight case studies including accident reconstruction, airport runway and airport inspection, bridge inspection, construction monitoring, dam/emergency management, traffic monitoring, rail mapping and bridge inspection, and rock slope inspection. These case studies served the purpose of evaluating the applicability of UAS for NH DOT, comparing UAS to existing methods, and analyzing barriers to UAS implementation.

CHAPTER 2: UAS AND TRANSPORTATION

Commercial remotely sensed datasets have tremendous value for a wide range of transportation-related activities, such as construction monitoring, cost decision support, and traffic monitoring, but their full potential can be constrained by inadequate temporal resolution, poor spatial resolution, and high acquisition costs. Unmanned Aerial Systems (UAS), also known as drones, are aircraft that do not carry a human pilot and are capable of flying either autonomously or with a remote control (Saranya, 2016). UAS have the potential to overcome the limitations inherent with traditional forms of remotely sensed data and in turn change the way this data are used in transportation planning, operations, maintenance, and development. Off the shelf UAS are relatively inexpensive to purchase, easy to operate with training, rapidly deployable, and provide high resolution data that cannot be matched by traditional platforms. The case studies carried out as part of this research project serve as a starting

point to improve the abilities of NH DOT to integrate UAS data and products into their decision making and operations.

One of the most common and straightforward ways in which UAS are being used in transportation activities is for traffic monitoring. In these cases, UAS can be used as an eye in the sky to provide transportation agencies with aerial footage of traffic. Some agencies have gone further and use UAS with the ability to identify, track, and monitor specific vehicles. From aerial footage of traffic, information can be extracted from the data such as densities, travel times, and vehicle quantity (Barmounakis, 2017). Although UAS can provide much valuable information, privacy issues are a concern and limitation.

UAS can also provide valuable survey or inspection information faster than traditional methods. An area that would have taken days to survey through manual methods, can be surveyed with UAS in a matter of hours. Not only does that save time, but money as well which can then in turn allow for more frequent inspections if needed. UAS can be flown in areas that may be impossible to reach or dangerous for humans to inspect. UAS provides a safer alternative to certain manual inspections. Not only can UAS capture aerial photos and videos, but the data can also be processed to create geospatial and 3-dimensional data that can then be used for analysis.

Although UAS has many benefits related to transportation activities, UAS also have limitations that need to be considered. The primary limitations of UAS are weather and battery life. Typical UAS platforms and sensors cannot be flown in precipitation as the platform and sensors are not water resistant. UAS also cannot be flown in high wind or gusty conditions. Wind speed maximums are specific to the UAS platforms as some platforms are better in wind than others. Battery life is the second major limiting factor in UAS as batteries limit flight times to typically less than an hour, limiting the amount of data that can be captured in a single flight. Other limitations in UAS are potential equipment malfunctions, privacy concerns, along with federal and local regulations.

UAS have historically been used for military, aerial photography, search and rescue efforts, mapping, and law enforcement applications. Technological advancements over the past decade have brought many improvements and features to UAS to the point at which the consumer-grade UAS can be obtained for a relatively low price. Some of these advances include autonomous flight, safety features such as a return home feature, and obstacle avoidance. UAS are likely going to evolve quickly given how much technology has already changed in the past several years. The most significant hardware evolution will likely be batteries as the limited flight time is one of the chief limitations of UAS. Although the commercial drone industry is still in its early stages, the trend is towards cheaper and more customizable commercial drones for specialized UAS platforms and sensors (Joshi, 2017).

UAS have been around for decades, but in the past few years, UAS have made leaps and bounds in improvement. UAS technology can be broken down into seven generations (AirDroneCraze, 2017):

- Generation 1: Remote control aircraft
- Generation 2: Manual piloting control, static design, fixed camera mount, video and photos
- Generation 3: Assisted piloting, static design, two-axis gimbals, HD video, basic safety features
- Generation 4: Autopilot modes, transformative design, three-axis gimbal (used for stabilization), 1080 HD video or higher, improved safety features
- Generation 5: Intelligent piloting, transformative design, 360-degree gimbals, 4K video or higher
- Generation 6: Intelligent piloting and full autonomy modes, commercial, safety and regulatory standards-based design, platform adaptability, automated safety modes such as anti-collision, airspace awareness

- Generation 7: Complete commercial suitability, fully compliant safety and regulatory standards based design, platform interchangeability, automated safety modes, enhanced intelligent piloting modes and full autonomy, full airspace awareness, collision avoidance, and auto actions.

CHAPTER 3: UNMANNED AIRCRAFT SYSTEMS WORKFLOW AND PROCEDURES

Below, we describe the workflow and procedures used for the application studies in this research project.

3.1 PROCEDURES

UAS Operations consisted of flying both fixed-wing and multi-rotor UAS to acquire data. These were followed by data processing steps to support the application areas, and the development of decision support tools. Below is the general workflow to generate the different UAS products (Figure 1). Fixed-wing and multi-rotor system operations are inherently different. There do, however, exist commonalities when it comes to the planning and preparation of UAS missions. The UVM UAS Team developed a set of procedures, checklists, and workflows, ensuring safe and effective UAS operations. For the 43 UAS flights that took place, there was only one major incident in which a fixed wing battery was knocked out of the UAS causing the UAS and the battery to fall from the sky. This was due to high winds and no person or equipment was damaged.

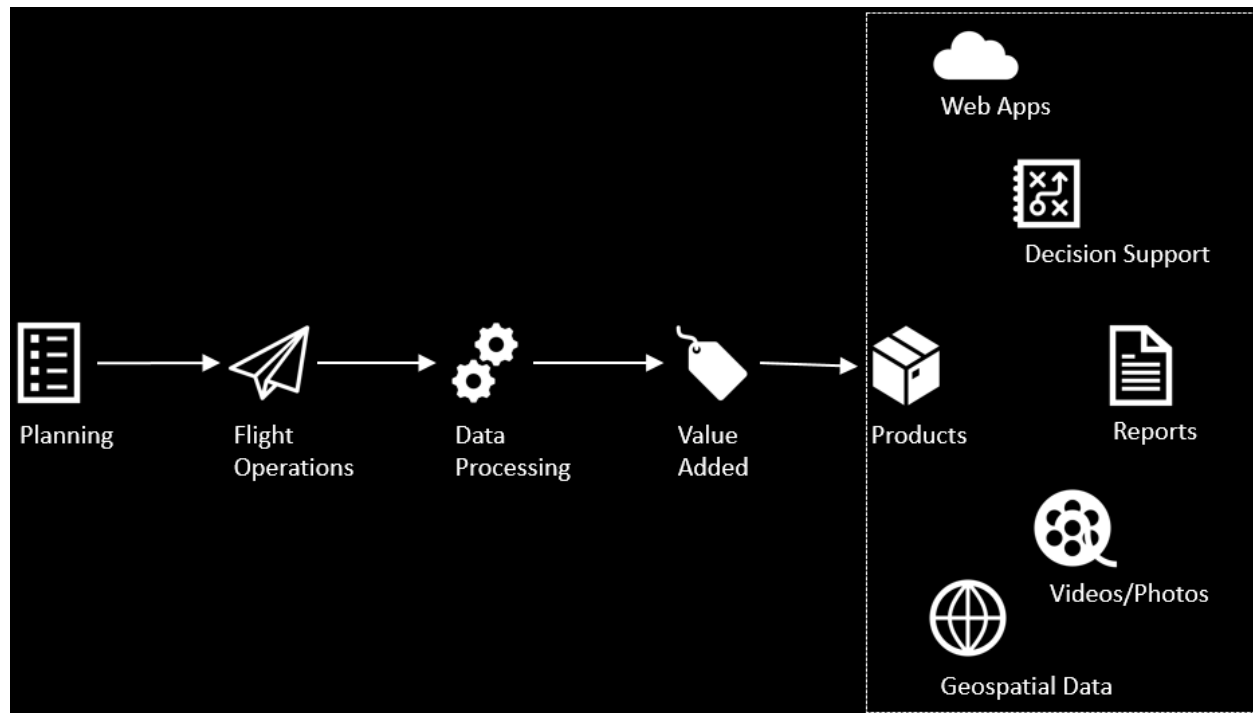


Figure 1. General workflow to generate the different UAS products.

3.2 CHECKLISTS

Three sets of checklists were generated for each case study: 1) mission planning, 2) flight operations, and 3) post-flight. These checklists and the associated applications provide a means by which to ensure accountability throughout the organization. The checklists were built using the Fulcrum platform (<https://web.fulcrumapp.com>) and Drone Logbook (<https://www.dronebook.com>). The benefit of the Fulcrum platform is that it provides an easy way to design, develop, and deploy cross-platform spatially-enabled applications (Figure 2). The applications

were built using the Fulcrum online interface then used on a variety of smartphones and tablets. Drone Logbook is used to log flight information and management of UAS.

The screenshot displays the 'UAV Mission Checklist (previewing)' interface. At the top, there's a yellow header bar with a red 'X' icon on the left and a green checkmark icon on the right. Below the header, the title 'UAV Mission Checklist (previewing)' is centered. Underneath, the text 'Untitled' is displayed. The main area features a map of the Northeast United States, including parts of Vermont, New Hampshire, and Maine. A red location pin is placed near Burlington, Vermont. Above the map, the text 'Click on the map to set the location' is visible. To the right of the map, there's a 'Done' button. Below the map, there's a 'Metadata' section with the following fields: 'Duration' (14 seconds (First Creation)), 'Location' (No Location Change), and 'Assigned' (- No Assignment -). Below the metadata section, there are three expandable sections: 'Mission Information', 'Day prior to flight', and 'Day of flight', each with a 'View' button. At the bottom, there's a 'Signature' field with a red asterisk and a 'Select File' button.

Figure 2. Example mission checklist.

3.3 UAS OPERATIONS

FIXED WING UAS OPERATIONS

The senseFly eBee, eBee RTK, and eBee Plus models were used for all fixed-wing UAS operations (Figure 3). Fixed-wing UAS operations consisted of three main phases: 1) flight planning, 2) launch, flight, and recovery, and 3) data processing.



Figure 3. The UVM UAS Team preparing for a flight with the senseFly eBee Plus.

Flight planning was performed using the eMotion software package (Figure 4). Constructing a flight plan is a user-driven process in which the operator establishes a polygon defining the flight area then defining key parameters such as percent overlap between flight lines, target resolution, maximum altitude, maximum operating radius, and launch/landing sectors.

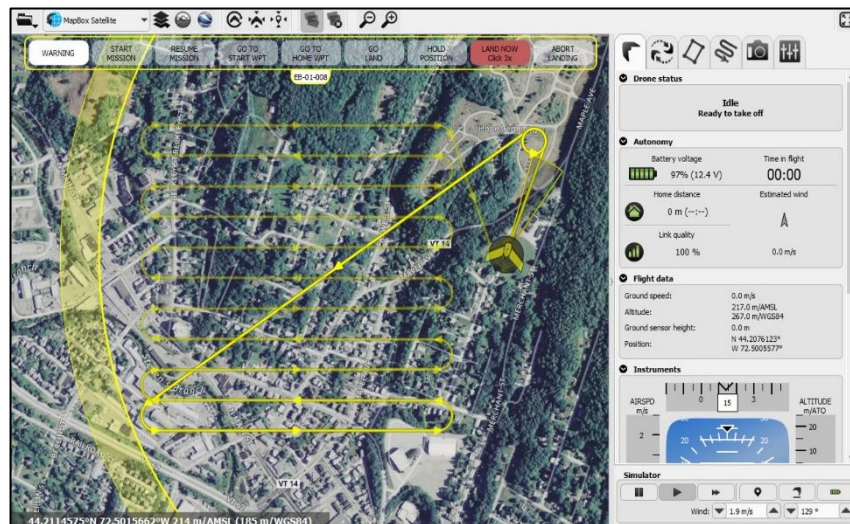


Figure 4. Sample flight plan generated for the eBee using the eMotion software package.

The flight itself is largely autonomous, with the UAS following the pre-programmed flight. An operator would only intervene in extenuating circumstances (e.g. abort a landing). A video showcasing UVM's fixed-wing flight operations is available on YouTube (https://youtu.be/_6hA831P4To).

Once the imagery has been collected and downloaded from the system, they are fed into Pix4D, a photogrammetric processing software package (Figure 5). Pix4D uses structure from motion combined with GPS and flight log information from the UAS to orthorectify the imagery, thereby removing distortions associated with the sensor and terrain. Pix4D yields a number of products including orthorectified raster imagery (Figure 6), 3D point clouds (Figure 7), and raster surface models. These products use standard, open file formats, enabling them to be viewed and analyzed in virtually any geospatial software package.

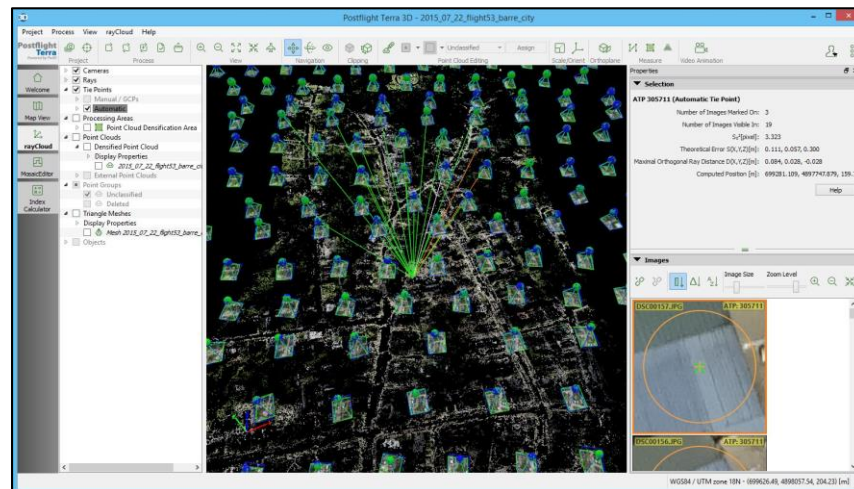


Figure 5. Photogrammetric processing using Pix4D.

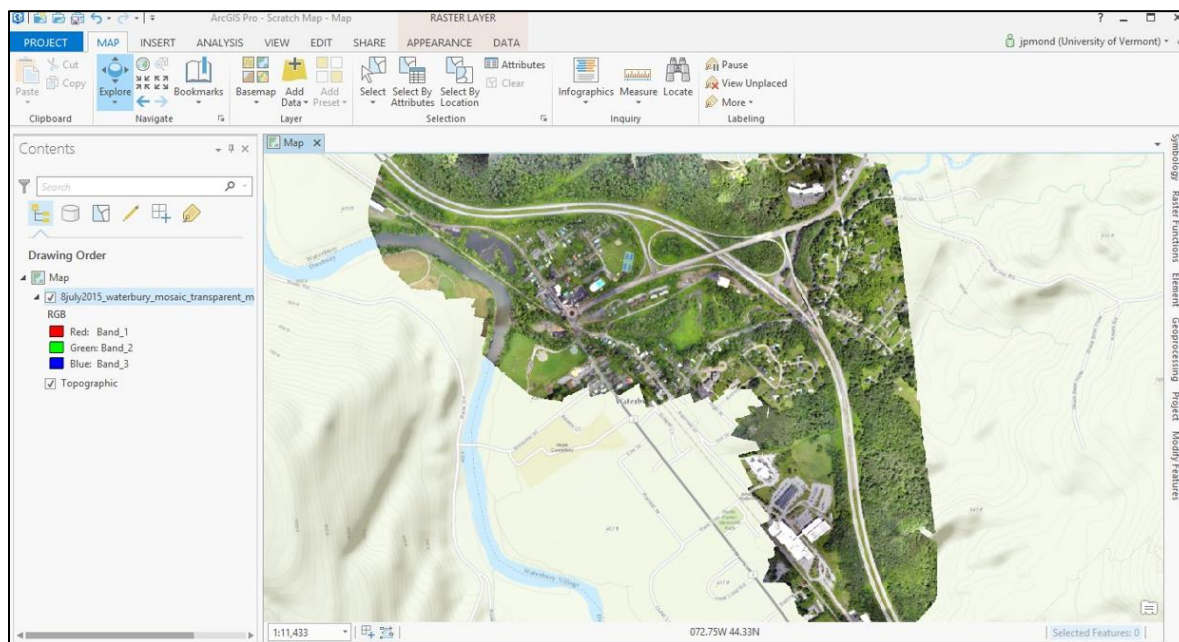


Figure 6. UAS Orthorectified image mosaic generated using Pix4D displayed in ArcGIS.

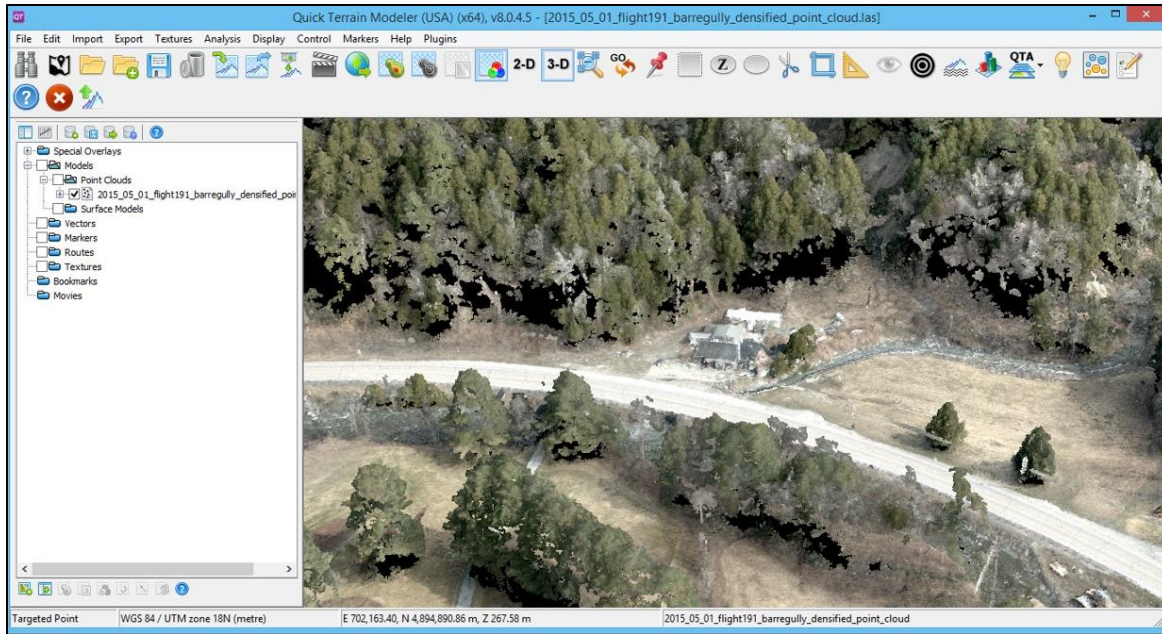


Figure 7. UAS 3D point cloud generated using Pix4D displayed in Quick Terrain Modeler.

MULTI-ROTOR UAS OPERATIONS

The multi-rotor system used for inspections in this project, the senseFly Albris, can be operated in both manual mode and a preplanned automated flight mode. Manual mode is most commonly used when conducting close-range inspections (Figure 8). In such cases, the data collection focus is on still images, videos, and thermal imaging. The operator will often work closely with the bridge inspector to capture data of points of interest. One of the unique capabilities of the Albris is that the camera can point up or down, enabling it to capture images of the tops or undersides of bridges (Figure 9).



Figure 8. The senseFly Albris in manual operation mode while carrying out a close-range inspection of a historic covered bridge.



Figure 9. Inspection photo of the underside of a railroad bridge captured by the senseFly Albris.

The purpose of the automated flight mode is to gather images with the appropriate properties to create a detailed 3D model. This process is virtually identical to flying the eBee in that flight planning is carried out in eMotion, followed by autonomous flight operations, and finally photogrammetric processing in Pix4D (Figure 10). While a UAS such as the senseFly Albris can acquire imagery from side look angle, thereby improving the quality of a 3D model for an individual structure, it can cover far less of an area in a single flight but in much more detail compared to a system like the eBee (Figure 11). A video showcasing UVM's multi-rotor flight operations is available on YouTube (<https://youtu.be/D-HyftUaQKc>).

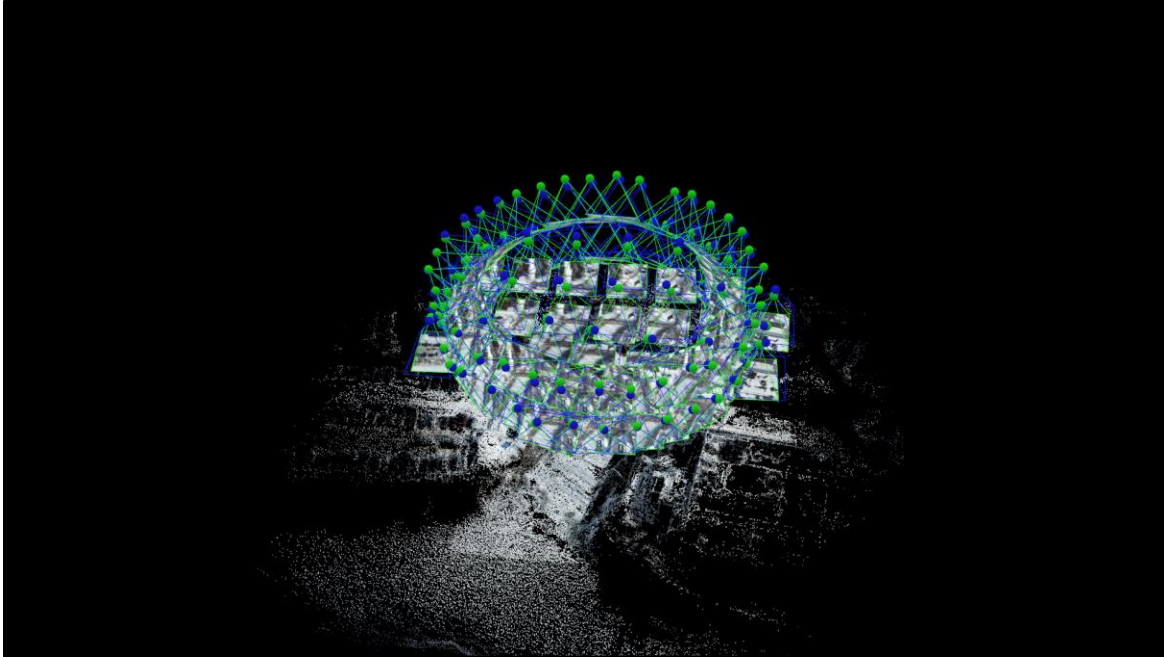


Figure 10. Pix4D layout showing the images collected of a bridge by the senseFly Albris UAS.



Figure 11. Detailed 3D model of a railroad bridge generated by the senseFly Albris during an autonomous flight operation.

The multi-rotor system used for the traffic monitoring, rock slope, and accident case studies in this project was the DJI Phantom 4 and can be used to capture aerial photos and videos. The DJI Phantom 4 is a quadcopter UAS platform with a high performance camera that can shoot video in 4K at 30 frames per second. The benefits of using this platform is that it takes under five minutes to set up the UAS for each flight.

CHAPTER 4: CASE STUDIES

4.1 OVERVIEW

Working with the stakeholder advisory committee and NH DOT, a list of case studies were established to serve the purpose of evaluating the applicability of UAS for NH DOT, comparing UAS to existing methods, and analyzing barriers to UAS implementation. Eight case studies were selected based on where UAS could play a key role in transportation-related tasks that could benefit NH DOT. The case studies were accident, airport and runway inspection, bridge inspection, construction monitoring, dam/emergency management, traffic monitoring, rail mapping & bridge inspection, and rock slope inspections.

Each case study consisted of UAS mission planning, UAS operations, UAS products, and data product transfer to NH DOT. The UAS mission planning identified the appropriate personnel, UAS platform(s), UAS sensors(s), supporting equipment, operating procedures, safety procedures, and regulatory requirements to operate the UAS successfully. Specifications on the desired end products and their formats were also developed at this stage. UAS operations were conducted for each one of the case studies. Flight operations consist of launch, data capture, recovery, along with any gathering of other ancillary information that was required. During UAS operations, NH DOT personnel were invited to participate in order to familiarize themselves with UAS flight operations, processes, and procedures. The UAS data collected during UAS operations was processed and products were generated. Processing of the UAS data generated primary products such as orthophoto mosaics, 3D models, videos, or still pictures. UAS processing ranged from compiling, editing, and posting video data to the photogrammetric processing of hundreds of individual geotagged photos. Other UAS products that involve additional processing or manipulation of the UAS data includes web-based maps, feature extraction, CAD/GIS integration, or aerial measurements. Data product transfer focused on providing UAS products to NH DOT stakeholders for evaluation, integration, and implementation.

In order to complete these studies, the UVM UAS Team had a large inventory of UAS equipment, software, and trained personnel. This included having multiple UAS platforms and sensors. The UAS Team had two quadcopter platforms with one being a specialized inspection UAS, four fixed-wing mapping UAS, and multiple true color sensors. In addition to multiple platforms, the UAS Team also had enough batteries for the UAS and additional equipment for a full day of flight operations. The UAS Team had specialized software to process and view the geospatial data. The Team also has 150 TB of dedicated high-performance network storage that is backed up daily to store the UAS data. During the case studies, the UVM UAS Team had five personnel with a remote pilot license and the necessary training to process and analyze the UAS data. Below is a graphic describing all of the equipment and resources the UVM UAS Team had to complete the case studies.

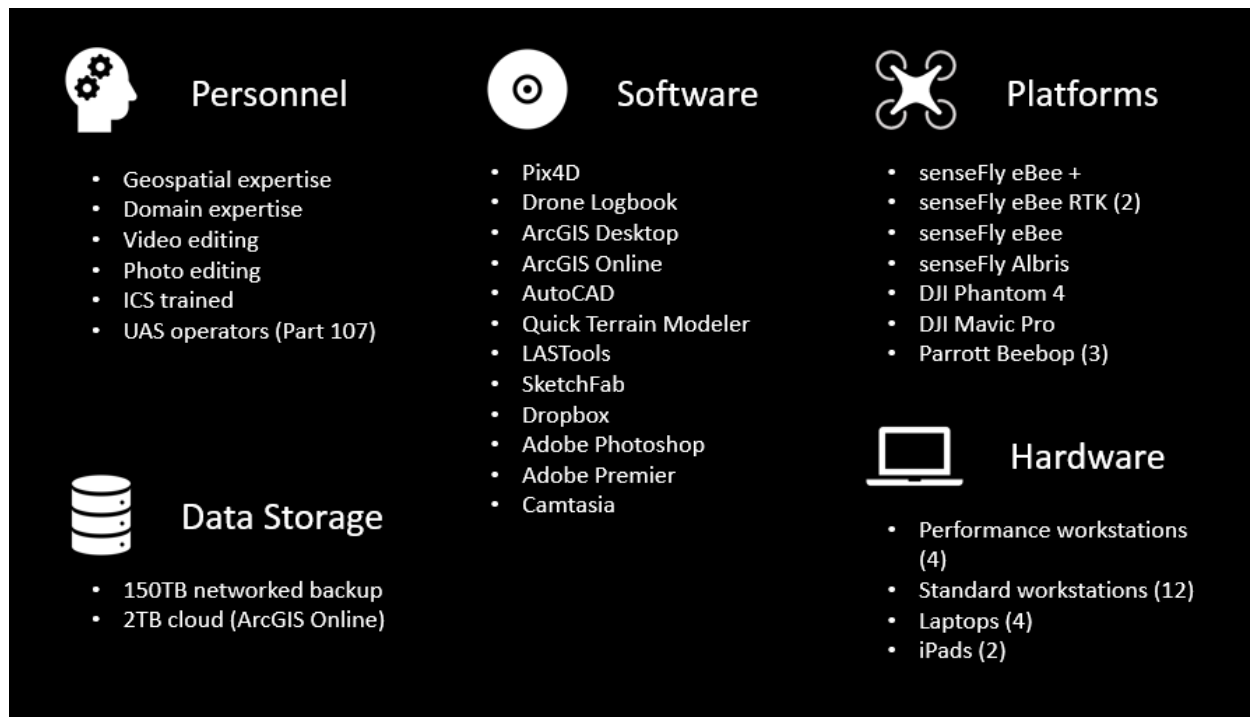


Figure 12. Graphic describing the equipment and resources the UVM UAS Team had to perform the case studies.

4.2 CASE STUDY: ACCIDENT

SUMMARY

On December 6, 2017, UAS were used to map a simulated car accident at the New Hampshire Motor Speedway in Loudon, New Hampshire. The purpose of this case study was to evaluate the strengths and limitations of using UAS in an accident response. The products of this case study include high resolution aerial imagery of the accident and surrounding areas. The UAS also collected aerial photos and videos of the accident. The UAS used for mapping was the senseFly eBee RTK which is a fixed wing platform that was used to collect detailed photographs from a bird's eye view to create imagery. The UAS team had five batteries for the senseFly eBee RTK with each battery capable of a ~20-minute flight. It took approximately 20 minutes to set up the UAS and flight plan for the first flight and then a few minutes between flights to switch out the batteries. In total, the senseFly eBee flew for about 30 minutes to capture the necessary photos for geospatial products. The UAS used to collect aerial photos and videos was the DJI Phantom 4, which is a quadcopter platform. The UAS team had four batteries for the DJI Phantom 4 with each battery capable of a 25-minute flight. Set up for each Phantom flight was under 3 minutes and it took under a minute to switch out each battery. Total time for the DJI Phantom 4 flights was about 30 minutes. The UVM UAS Team used two UAS platforms because of the different capabilities the senseFly eBee and DJI Phantom 4 perform. The senseFly eBee is used to generate geospatial products while the DJI Phantom is better for capturing oblique photos and videos.

METHODS

The UAS Team arrived to the simulated accident site on the morning of December 6, 2017 in Loudon, NH at the New Hampshire Motor Speedway. The UVM UAS Team set up flight operations for the DJI Phantom 4 first to acquire photos, videos, and virtual reality products of the accident (Figure 13). Flight operations for the DJI

Phantom were completed after 16 minutes. Weather conditions of the day were overcast, about 35 degrees, and low winds.



Figure 13. The UVM UAS Team preparing for a flight with the DJI Phantom 4.

After concluding the flight operations for the DJI Phantom 4, the team set up flight operations for the eBee RTK from a field located near the accident (Figure 14). In a single flight, the senseFly eBee RTK captured 105 photos with a total flight time of 15 minutes. Due a loss of RTK connectivity during the flight due to technical issues, a second flight was required to ensure the team was collecting accurate data. The second flight was only 11 minutes and was focused on those areas where the previous flight had less accurate data. After flight operations with the senseFly eBee RTK were complete, the team opened up the photos from the drone to look at the accident aerial photos. With under an hour of work, the UAS team acquired aerial data of the accident for responders.



Figure 14. The UVM UAS Team preparing for flight operations of the senseFly eBee RTK.

Data processing involved taking the 183 images captured by the eBee RTK UAS to generate 2D and 3D geospatial products using digital photogrammetric techniques. The initial processing, which was carried out immediately after flight operations using the eMotion software, synchronizes the images with the flight log on the UAS. Generating the actual geospatial products was carried out using Pix4D, a state-of-the-art digital photogrammetric software package. Pix4D first generated a 3D model of the area using the imagery, then used that 3D model to generate a seamless orthorectified image mosaic. A report was also created that provided information on the calibration, geolocation, and point cloud densification details.

The processing for this case study took approximately two and a half hours to complete. Once completed the total file size of the output products was 4.4 GB.

PRODUCTS

Geospatial products included orthomosaic imagery and 3D point cloud (Figure 15). Other products include aerial photos, videos, and [virtual reality](#) of the accident (Figure 16). The [3D point cloud](#) was uploaded to an online platform for accessibility. The UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 17).



Figure 15. Geospatial products of the accident case study. The orthomosaic imagery is on the left and the 3D point cloud is on the right.



Figure 16. Products of the accident case study. The top left is an aerial photo captured, top right is one of the videos captured, and the bottom is the [virtual reality](#) product.



Figure 17. Screen capture of the accident case study [ESRI Story Map](#).

STRENGTHS

UAS can be used to quickly document the accident which allows for responders to open the road sooner as opposed to documenting the accident from the ground. Using a UAS for documentation cut the time spent on the accident site by one fifth (Pix4D, 2017). Virtual reality products created during this case study provide aerial views of the accident in about a five minute turn around. This may be valuable for responders to see the extent of the accident while on site. Not only do the UAS images help describe the accident, but data derived from UAS like the imagery and point cloud provide measurable products that can be utilized in court (Pix4D).

LIMITATIONS

Fixed-wing flight operations, while posing less of a risk if an equipment failure were to occur took longer to set up than multi-rotor flight operations. In addition, a suitable staging area is required for fixed-wing launch and recover.

This case study may require investments in UAS platforms and sensors that can be fully operational in precipitation and windy conditions as accidents don't always happen on sunny, low wind days.

4.3 CASE STUDY: AIRPORT RUNWAY AND AIRSPACE INSPECTION

SUMMARY

On June 2 and October 4, 2017, UAS were used to conduct an airport inspection that encompassed the areas and data normally obtained during an Annual Airport Safety Inspection including the runway and approach surface airspace. UVM's UAS team worked closely with NH DOT, the FAA, and Jaffrey Airport management to acquire data of the airport. As UAS flight operations would occur on an active airfield safety was a top priority. Protocols were developed so that UAS operations would not interfere with planned airport and aircraft operations. UAS were deployed from several areas at the airport to keep line of sight of the UAS at all times. The UAS platform used for this case study was a fixed wing UAS called the senseFly eBee Plus to collect detailed photographs from a bird's eye view. Thousands of photographs from a few flights are stitched together in an orthographically correct image mosaic that is fully georeferenced. The UAS team had seven batteries for the eBee Plus with each battery capable of a ~40-minute flight. Flight operations were conducted after a 10-minute safety briefing with the airport manager and NH DOT staff. It took about 20 minutes to set up the drone and flight plan for the first flight and then a few minutes between flights to switch out the batteries. Weather conditions for June 2nd, 2017 were little cloud cover, around 65 degrees, and high winds. Weather conditions for October 4th, 2017 were no cloud cover, 70 degrees, and moderate wind levels.

METHODS

The UAS Team arrived to Jaffrey Airport on the morning of June 2, 2017. The UVM UAS Team set up flight operations for the eBee Plus to the side of the runway. In two flights, the eBee Plus captured 1068 photos over a 210-acre area with a total flight time of 53 minutes. This included the entire runway area, but high winds caused an equipment malfunction and made subsequent flight operations unsafe (Figure 18). It was decided to complete this case study on a less windy day.



Figure 18. The UAS Team walking back to the UAS staging area after the retrieving the senseFly eBee Plus after the equipment malfunction.

On October 4, 2017, the UAS Team returned to acquire imagery of the northern and southern runway approaches. After completing the southern runway approach, the UVM UAS Team set up in a field north of the runway to capture images of the northern approach. In five flights, the eBee Plus captured 1058 photos with a total flight time of 115 minutes for both runway approaches.

Data processing involved taking the 2,126 images captured by the eBee Plus UAS to generate 2D and 3D geospatial products using digital photogrammetric techniques. The initial processing, which was carried out immediately after flight operations using the eMotion software, synchronizes the images with the flight log on the UAS. Generating the actual geospatial products was carried out using Pix4D. Pix4D first generated a 3D model of the area using the imagery, which was then used to generate a seamless orthorectified image mosaic. A report was also created that provided information on the calibration, geolocation, and point cloud densification details.

The processing for this case study took approximately 31 hours and 48 minutes to complete. Once completed the total file size of the output products was about 68 GB. The processing was run on a computer with 64 GB RAM and 4 core CPU, which is why the processing time is longer than other case studies. All other case studies were processed on a computer with 128 GB RAM and 28 core CPU.

PRODUCTS

Geospatial products included orthomosaic imagery, digital surface model, digital elevation model, and 3D point cloud (Figure 19). Features can also be extracted from the geospatial products such as damaged areas and pavement markings (Figure 20). The UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 21).

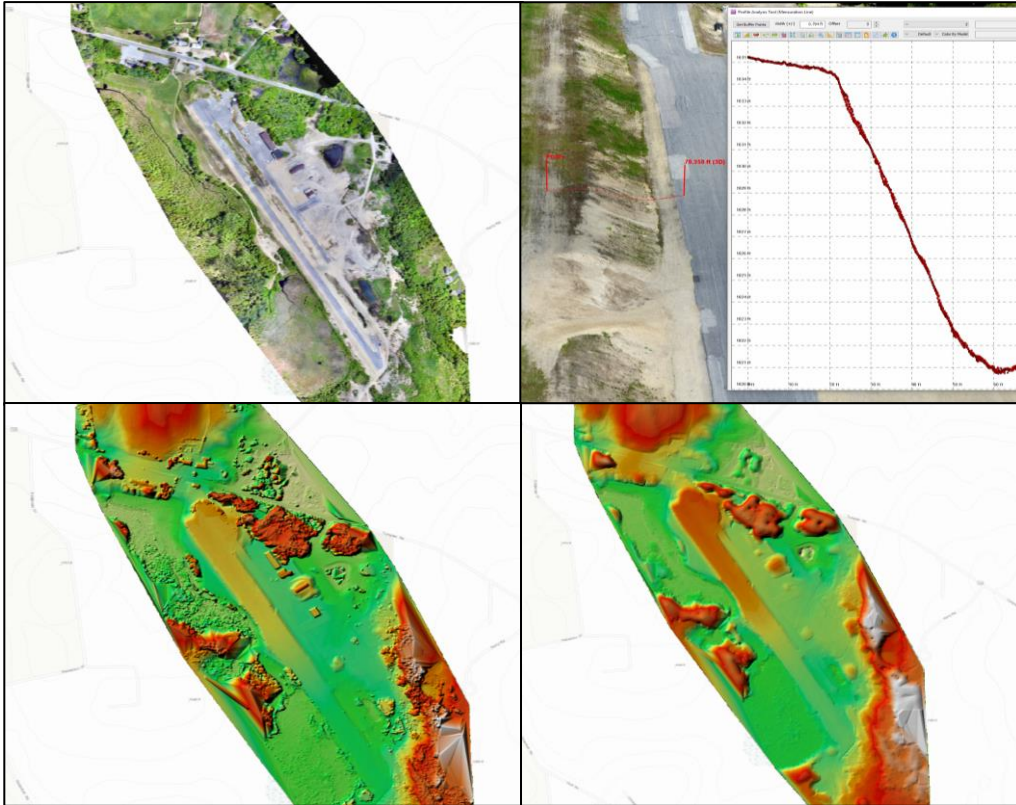


Figure 19. Geospatial products of the aeronautics case study. Upper left is the orthomosaic, upper right is the 3D point cloud, lower left is the digital surface model, and the lower right is the digital elevation model.

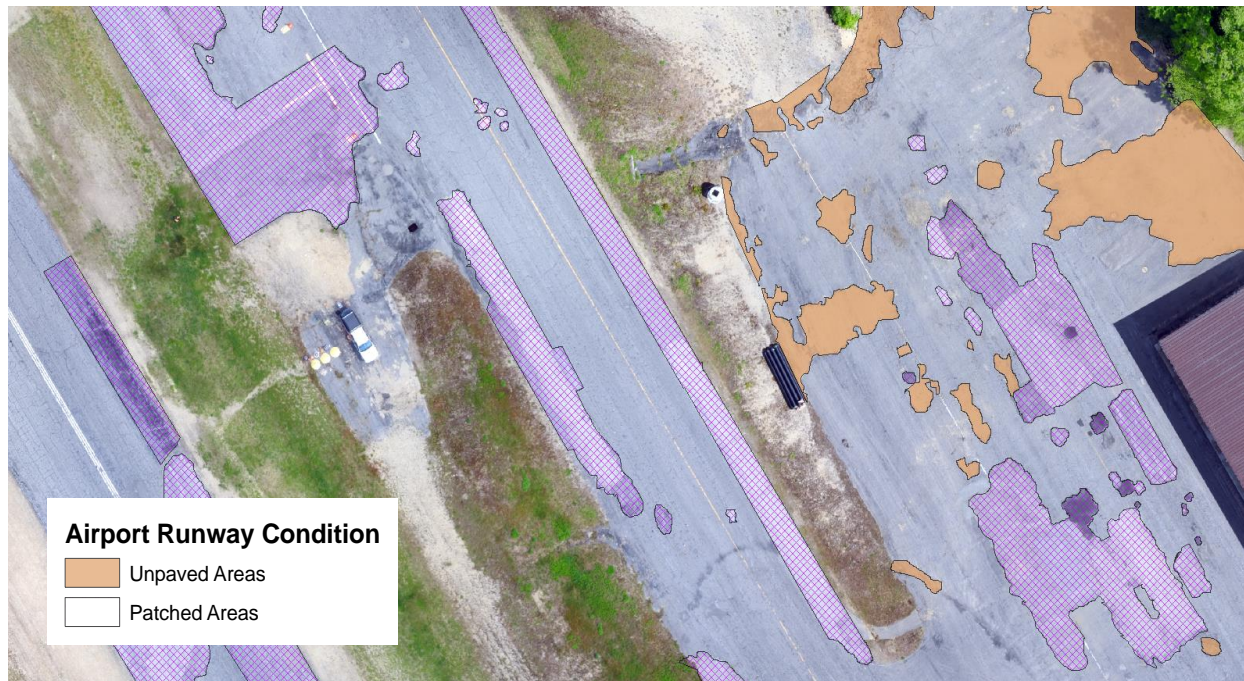


Figure 20. Unpaved and patched areas of the airport runway have been mapped based on the orthomosaic imagery.

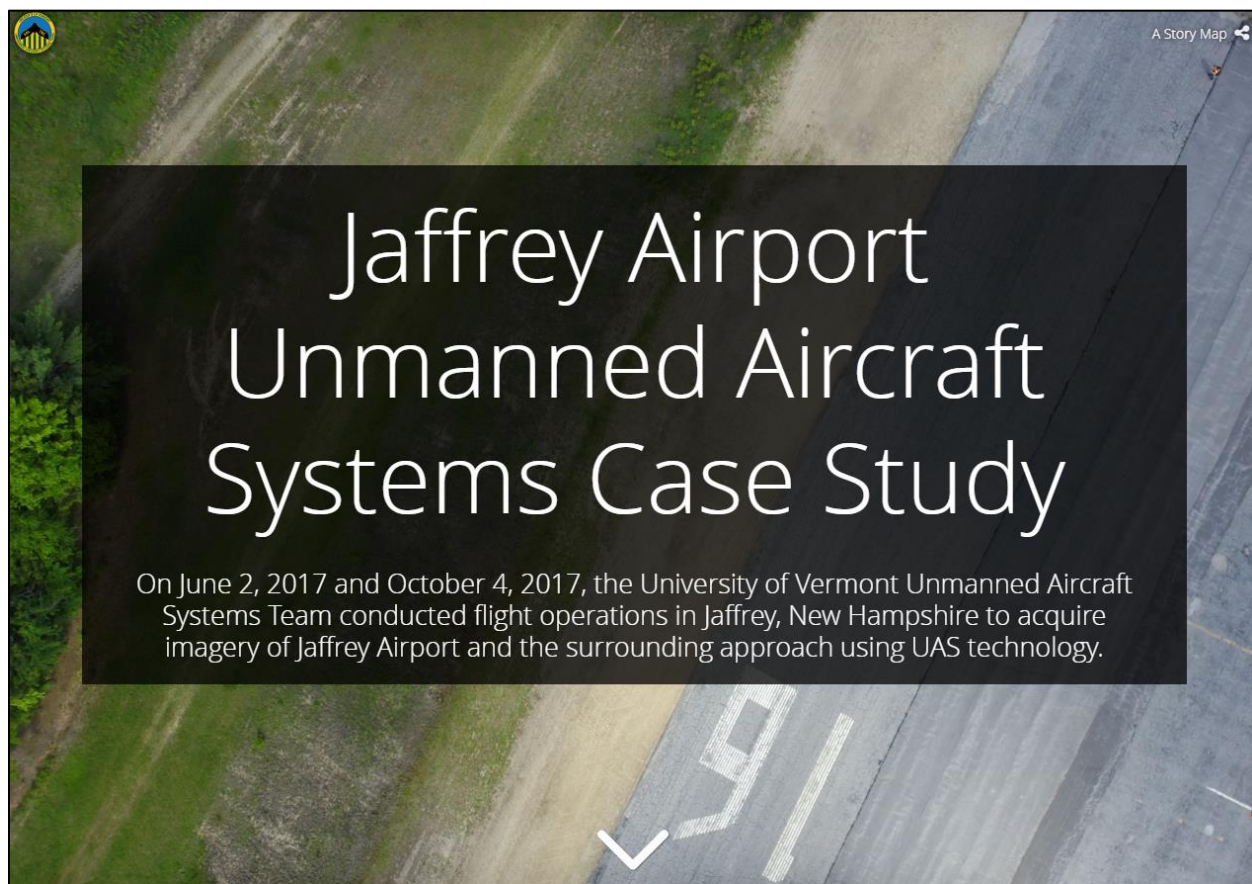


Figure 21. Screen capture of the airport runway and airspace inspection case study [ESRI Story Map](#).

STRENGTHS

Performing surveys with UAS is safer than having personnel carry out manual inspections. UAS pilots can stay off of the active runways while performing the inspection of runway conditions. Traditional inspections require putting personnel in the middle of active runways during the survey (McFall, 2017). Data derived from UAS can be used for runway pavement inspections that typically takes hours to do with traditional methods. The resolution of the UAS imagery was 1.8 cm, in comparison to the ESRI base map of 30 cm, so fine cracks in the runway could easily be detected using the UAS imagery. UAS data can be viewed in 3D setting back in the office where precise measurements on the horizontal and vertical scale can be made.

LIMITATIONS

UAS missions occurring on active airports require additional safety steps and expertise to ensure UAS flights do not interfere with manned aircraft. For safety reasons, UAS operations may be limited to only tethered operations. Tethered operations are when the UAS is attached to a leash on the ground to ensure the UAS does not get in the way of manned aircrafts. Although this limitation is often not required, it is something to be aware of that may be required at certain airports (Airsite, 2016). Obtaining an airspace authorization through the FAA will be necessary in many airports, but notification and coordination with airport management may be all that's needed at other airports.

4.4 CASE STUDY: BRIDGE INSPECTION

SUMMARY

On August 8, 2017, UAS were used to inspect a bridge in Lebanon, New Hampshire. The purpose of this case study was to provide high resolution inspection photos and provide aerial perspective photos and videos of the bridge. The UAS used for this study was the senseFly Albris, a quadcopter UAS inspecting platform. The DJI Phantom 4 was also used to acquire additional aerial photos and videos. 2 different UAS platforms were used in this case study as the senseFly Albris and DJI Phantom 4 have slightly different capabilities. The Albris has a 360 gimbal which is better suited for capturing inspection photos because the drone can fly underneath the bridge and can capture data on the underside of the bridge. Weather conditions on the day were warm and low winds with little clouds in the sky.

METHODS

This case study occurred on August 8, 2017 at a bridge in Lebanon, NH on I-89. The UVM UAS Team first conducted flight operations using the senseFly Albris to capture UAS inspection photos of the bridge and surrounding area. The UVM UAS Team conducted three flights using the senseFly Albris. Then, the UAS Team conducted one flight using the DJI Phantom 4 to acquire aerial photos and videos of the bridge.

The data processing for this case study involved creating a compiled video of the videos captured by the DJI Phantom 4. No processing was necessary for the inspection photos as geospatial products were not created.

PRODUCTS

Products included high resolution inspection photos, aerial photos, and aerial videos (Figure 22 and Figure 23). A compiled video of inspection photos and aerial photos was uploaded to YouTube for accessibility. The UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 24).



Figure 22. High resolution inspection photos acquired during the bridge inspection case study



Figure 20. Screen capture of the video created for the bridge inspection case study.

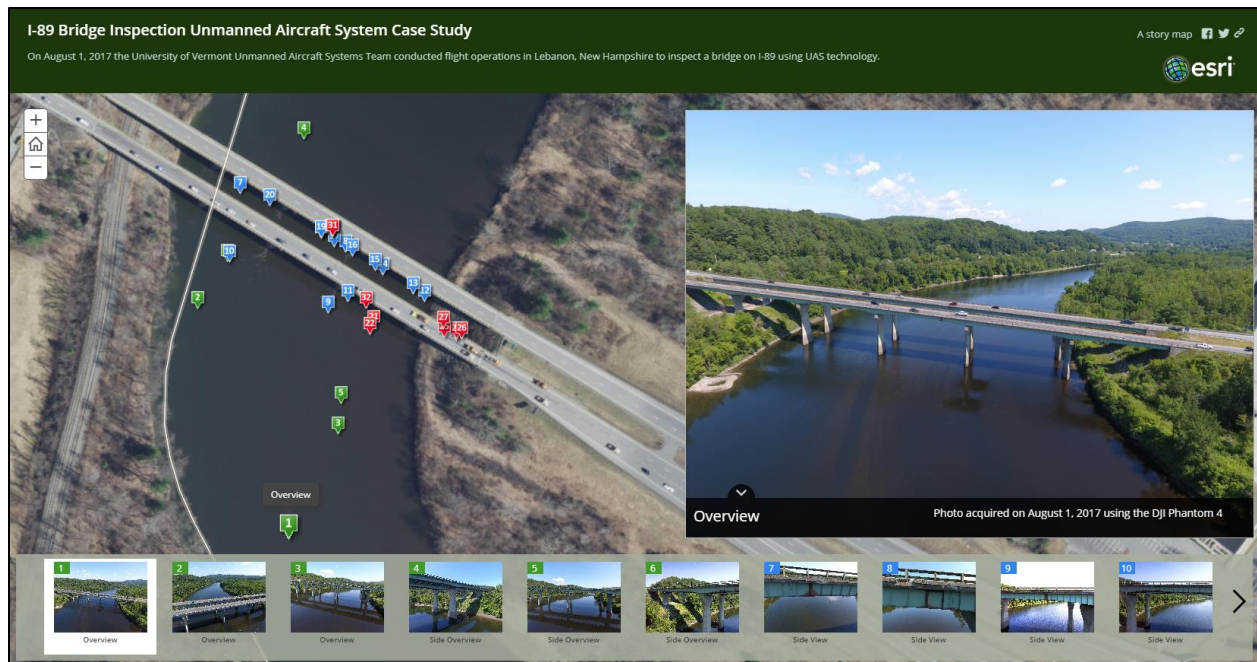


Figure 24. Screen capture of the I-89 bridge inspection [ESRI Story Map](#)

STRENGTHS

The use of UAS for monitoring or screening purposes have the capability to acquire accurate data in a timely manner. The DJI Phantom 4 can precisely hover and sends a live video feed to the remote control so the pilot has the ability to focus on areas of interest easily. The DJI Phantom 4 also takes little time to set up, where the UAS can be ready to fly in under five minutes.

The videos can be uploaded to YouTube that enables anyone with a web browser to examine the traffic videos. The videos uploaded were private allowing only people with the specific URL to view the videos.

A bridge monitoring or screening inspection using UAS technologies is significantly cheaper than using traditional methods. The Minnesota Department of Transportation conducted a cost comparison based on the inspection of Duluth's Blatnik Bridge. During a typical bridge inspection, this bridge would require four inspection vehicles, an 80 foot man-lift, and require eight inspection days. To perform this bridge inspection using traditional methods would total to about \$59,000. The cost of using UAS to inspect the same bridge would cost \$20,000 with only 5 days onsite. That is nearly a \$40,000 cost difference between the two approaches. Bridge inspections done with UAS can be performed without closing down traffic on the bridge (Wells). No costs were calculated or provided in this study.

UAS provides a unique perspective as the UAS can move its camera in almost any direction including the under sides of bridges.

LIMITATIONS

UAS cannot be used to independently inspect a bridge, but can be used as a tool for bridge inspectors to view difficult to reach areas. UAS can also be used to help bridge inspectors screen for bridge segments that need more intense manned inspections. Measurements can be obtained from UAS data, but hands on inspection like cleaning

and testing cannot be replaced by UAS (Wells). For bridges within controlled airspace, additional coordination and planning is needed to ensure proper authorization is in place.

4.5 CASE STUDY: CONSTRUCTION MONITORING

SUMMARY

On July 6, 2017, UAS were used to map an active construction area in Derry and Windham, New Hampshire. The purpose of this case study was to provide high-resolution aerial imagery of the construction project #14633B and surrounding areas. The UAS used for this case study was the senseFly eBee Plus, a fixed-wing UAS platform. The UVM UAS Team had seven batteries for the eBee Plus with each battery capable of a ~40 minute flight. It took about 20 minutes to set up the UAS and plan for the first flight, then a few minutes between flights to switch out the batteries. Weather conditions that day were in the low 80's, winds were around 8 miles per hour, and scattered clouds.

METHODS

The UVM UAS Team arrived at the construction area on the morning of July 6, 2017 in Derry and Windham, NH (Figure 25). In three flights, the eBee Plus captured 1032 photos over a 220 acre area with a total flight time of 1 hour and 5 minutes.



Figure 25. The UVM UAS Team preparing for a UAS flight with the senseFly eBee Plus.

Data processing involved taking the 1032 images captured by the senseFly eBee Plus UAS to generate 2D and 3D geospatial products using digital photogrammetric techniques. The initial processing, which was carried out immediately after flight operations using the eMotion software, synchronizes the images with the flight log on the

UAS. Generating the geospatial products was carried out using Pix4D. Pix4D first computed a 3D model of the area using the imagery, then used that 3D model to generate a seamless orthorectified image mosaic. A report was also created that provided information on the calibration, geolocation, and point cloud densification details.

The processing for this case study took approximately two and a half hours to complete. Once completed the total file size of the output products was 50GB. The processing was run on a computer with a 28-core CPU and 128GB of RAM, which greatly reduced the time it took to complete processing compared to the aeronautics case study.

PRODUCTS

Geospatial products included orthomosaic imagery, digital surface model, digital elevation model, and 3D point cloud (Figure 26). The [3D point cloud](#) was uploaded to Sketchfab, an online platform, for accessibility. Using the digital surface model, volumes can be estimated (Figure 27). The UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 28).

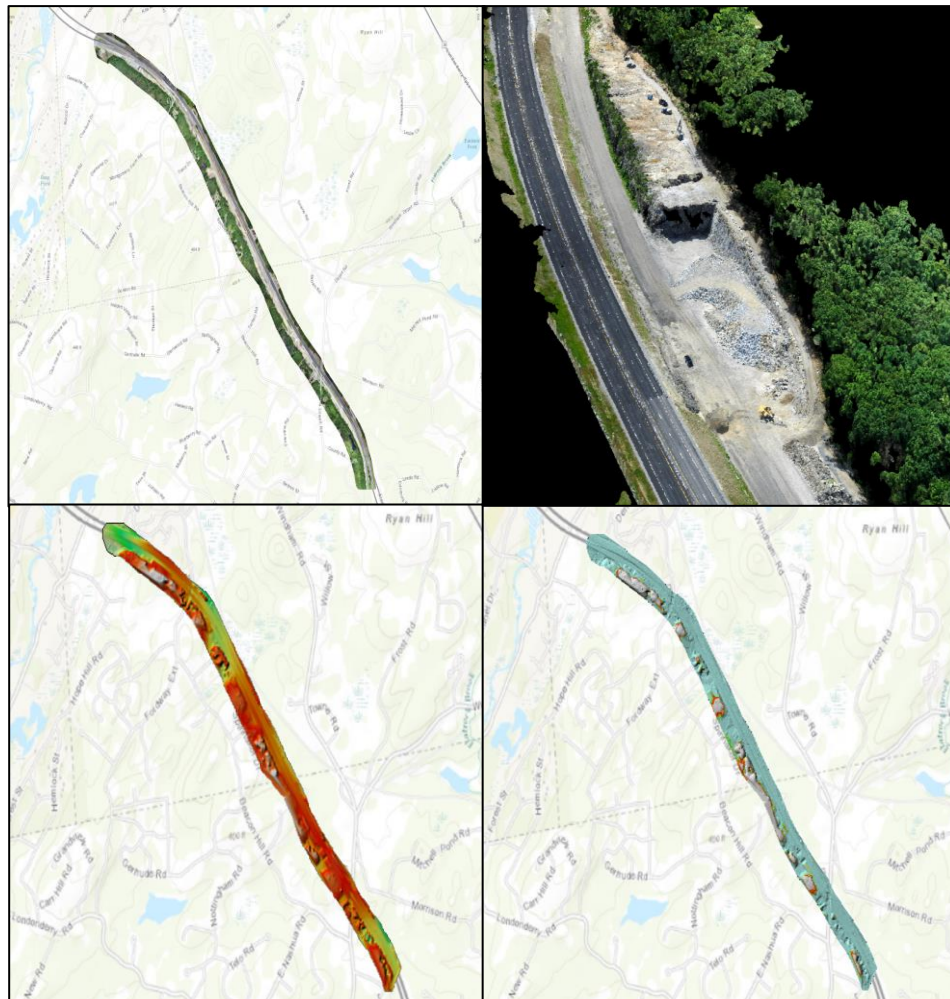


Figure 26. Geospatial products of the construction monitoring case study. Upper left is the orthomosaic, upper right is the 3D point cloud, lower left is the digital surface model, and the lower right is the digital elevation model.

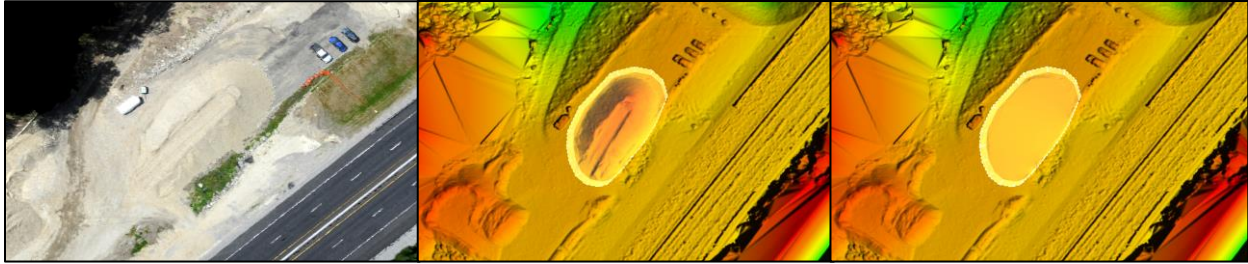


Figure 27. Volumes of quantities can be estimated based on the digital surface model. The image on the left shows the 3D point cloud of a stock pile, the middle image shows the area of interest to calculate the volume, and the right is the flattened area of interest. The volume can then be calculated based on the flattened area and original model.



Figure 218. Screen capture of the construction monitoring case study [ESRI Story Map](#).

STRENGTHS

The use of UAS on construction sites allows for the visibility and monitoring of construction progress. Imagery collected every week or two helps visualize and track the progress but can also improve compliance activities and invoicing through more accurately monitoring work progress. Regular flights over construction sites allow everyone involved in the project that may not be on site every day to view the status on construction progress (Higgins). UAS can also increase safety on construction sites by inspecting potentially hazardous areas before putting people and contracting equipment in that area.

The digital surface model derived from UAS can be used to accurately estimate the volume of stockpiles on construction sites. With centimeter grade accuracy, design plans can be overlaid with the drone imagery to ensure the construction is being done correctly (Higgins, 2017).

LIMITATIONS

May need to apply for a waiver to fly over people as construction operations would need to be paused during flight operations under current FAA regulations. Construction sites that are located within controlled airspace, the UAS pilot may also need to apply for a waiver to fly in controlled airspace.

4.6 CASE STUDY: DAM / EMERGENCY MANAGEMENT

SUMMARY

On July 19, 2017, UAS were used to map a dam and inspect priority areas of the dam in Pittsburg, New Hampshire. The purpose of this case study was to perform aerial reconnaissance of Murphy Dam on the Connecticut River in Pittsburg, New Hampshire, and the potential areas at the dam that could be damaged due to a natural or man-made disaster. Two UAS were used for this study: the senseFly Albris and the senseFly eBee Plus. The UAS used for collecting imagery of the overall area was the senseFly eBee Plus, a fixed-wing platform. The senseFly Albris was used to perform the close-range inspection of priority areas. The senseFly Albris is a multi-rotor UAS can acquire perspective views and can fly in hard to reach areas to allow for easy, remote inspection of structures with difficult access. It is particularly valuable for capturing information on the underside of structures as the camera can look up and down. The UAS team had seven batteries for the senseFly eBee Plus with each battery capable of a ~40-minute flight. It took about 20-minutes to set up the UAS and flight plan for the first flight and then a few minutes between flights to switch out the batteries. The UVM UAS Team had four batteries for the senseFly Albris with each battery capable of about a 20-minute flight. Wind conditions were about 8 miles per hour, temperature was in the high 70 degrees, and little to no cloud cover.

METHODS

The UVM UAS Team arrived at Murphy Dam on the morning of July 19, 2017 in Pittsburg, New Hampshire. The UVM UAS Team set up flight operations for the senseFly eBee Plus on a baseball field across from the dam. In a single flight, the senseFly eBee Plus captured 565 photos in a 120-acre area with a total flight time of 41 minutes. After flight operations of the senseFly eBee Plus were complete, the UVM UAS Team conducted flight operations with the senseFly Albris to obtain photos of the priority areas of the dam and surrounding area (Figure 29). Photos of the area were also captured so users can see the dam from a bird's eye view. The UVM UAS Team also collected enough data to create derived geospatial products.



Figure 229. The UVM UAS Team performing flight operations with the senseFly Albris.

Data processing involved taking the 565 images captured by the senseFly eBee Plus to generate 2D and 3D geospatial products using digital photogrammetric techniques. The initial processing, which was carried out immediately after flight operations using the eMotion software, synchronizes the images with the flight log on the UAS. The geospatial products were generated using Pix4D. Pix4D first computed a 3D model of the area using the imagery, then used that 3D model to generate a seamless orthorectified image mosaic. A report was also created that provided information on the calibration, geolocation, and point cloud densification details.

The processing for this case study took approximately two and a half hours to complete. Once completed the total file size of the output products was 50GB. The processing was run on a computer with 28-core CPU and 128GB of RAM.

PRODUCTS

Geospatial products included orthomosaic imagery, digital surface model, digital elevation model, and 3D point cloud (Figure 30). Using the digital elevation model, contour lines can be generated (Figure 31). High resolution inspection photos of priority areas are also a product for this case study (Figure 32). The [3D point cloud](#) was uploaded to an online platform for accessibility. UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 33).

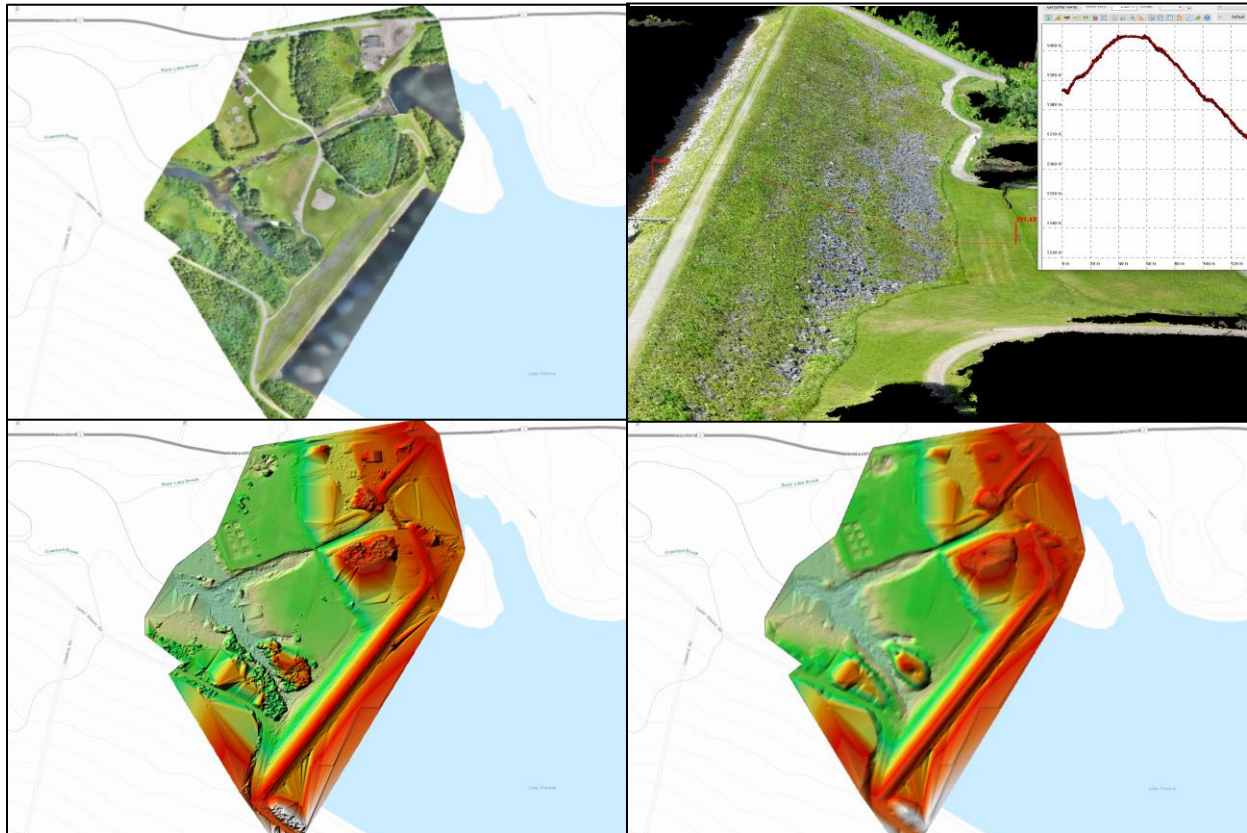


Figure 30. Geospatial products of the dam case study. Upper left is the orthomosaic, upper right is the 3D point cloud, lower left is the digital surface model, and the lower right is the digital elevation model.

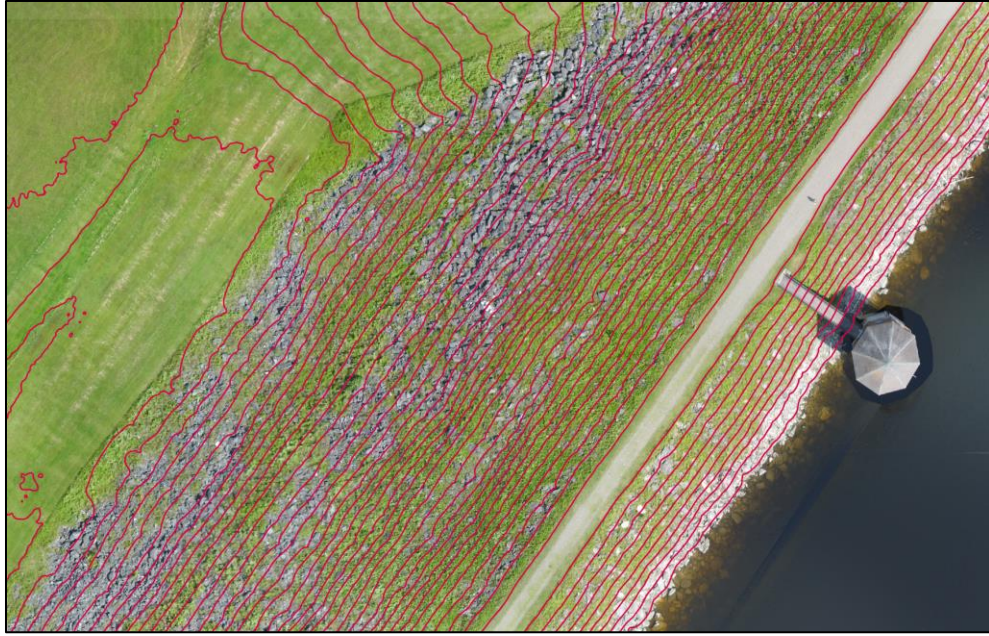


Figure 231. Contours can be calculated through the digital elevation model.

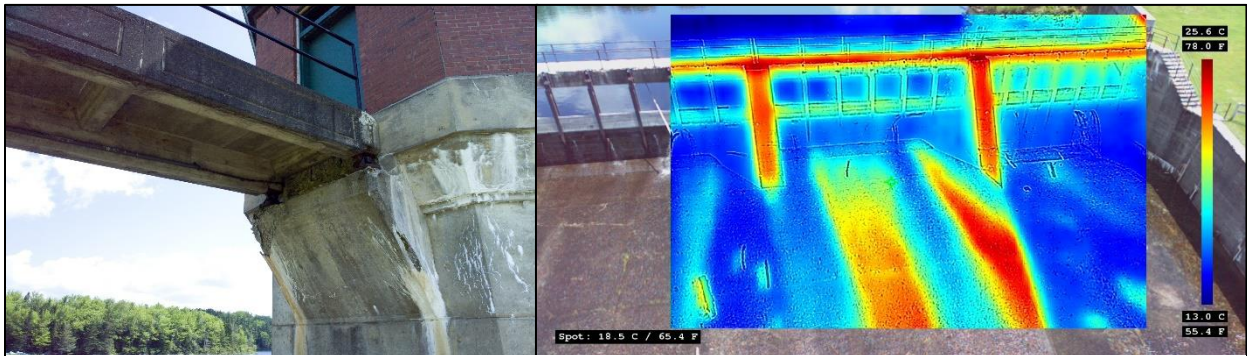


Figure 242. High resolution inspection photos captured during the dam case study. The senseFly Albris UAS is able to collect true color photos and videos in addition to thermal images.



Figure 33. Screen capture of the dam case study [ESRI Story Map](#).

STRENGTHS

The resolution of the UAS imagery was exactly 2.5 cm, in comparison to the ESRI base map of 30 cm, so fine details could easily be detected using the UAS imagery. UAS data can be viewed in a 3D setting where precise measurements on the horizontal and vertical scale can be made. Contour lines were easily created using the UAS elevation products, saving time and money than using traditional methods

UAS used to acquire inspection photos can access locations that cannot be done manually. These UAS have the ability to hover over an area of interest for measurements. Regular monitoring of a dam's infrastructure is critical. By acquiring imagery and inspection photos regularly, the data can be compared to historical records to monitor and track signs of degradation. UAS can be used to determine the limits and extent of damage to public works after a disaster occurs. Documenting damage can help facilitate situational awareness and cost estimates. UAS offer a safe, cost-effective way to inspect dams compared to traditional methods like rope-access inspections. Rope-access inspections are expensive with many inspections costing upwards of \$10,000 for one site. UAS can do similar work for a fraction of that (Tennessee Valley Authority, 2016).

LIMITATIONS

UAS cannot independently perform a dam inspection, but it can provide valuable information that an inspector may not acquire through traditional methods due to safety or the inability to inspect a hard to reach area by hand (Tennessee Valley Authority, 2016).

The UAS also acquired thermal inspection photos for this case study. Although thermal can be a valuable product when capturing data, in this case the thermal data spatial resolution was too coarse to analyze any details.

4.7 CASE STUDY: TRAFFIC MONITORING

I-95 TRAFFIC MONITORING

SUMMARY

On April 28 and April 30, 2017, UAS were used to monitor traffic on I-95 by the Piscataqua Bridge from 1430 to 1630 in Portsmouth, New Hampshire. UVM's UAS team worked with local agencies to acquire footage of the vehicle traffic of I-95 that day. UAS were deployed from several areas of interest north and south of the Piscataqua Bridge and recorded continuous aerial videos of traffic for five to ten minutes. The UAS used for this study was the DJI Phantom 4 which is a quadcopter platform with a high-performance camera that can shoot video in 4K at 30 frames per second. The UAS team had four batteries for the DJI Phantom with each battery capable of a ~25-minute flight. It took under five minutes to set up the UAS for each flight. The use of UAS for traffic monitoring allows for acquisition of localized spatial information in a timely manner. Weather conditions on April 28th were 7 mile per hour winds, scattered clouds, and temperature was in the mid-70s. On April 30th, weather conditions were 8 mile per hour winds, cloudy, and temperature was in the mid-40s. On April 30th, flight operations were concluded due to precipitation starting.

METHODS

This case study occurred on two high-traffic days where lanes were closed for construction, Friday April 28th, 2017 and Sunday April 30th, 2017. On April 28th, the UVM UAS Team arrived at 42 Ranger Way Portsmouth, New Hampshire to discuss plan of action at 1430. At 1500, UAS operations hovered over a point at 43.074646, -70.780981. The UAS took three videos focused on both north-bound and south-bound traffic totaling ~7 minutes. At 1530, UAS video was recorded while it hovered over a point at 43.083269, -70.773330 for ~5 minutes. Video was focused on north-bound traffic. At 1540, UAS operations hovered over a point at 43.085053, -70.772788 for ~6 minutes. Video focused on north bound traffic and vehicles entering I-95 north at exit 7. At 1620, UAS video was recorded while it hovered over a point at 43.068892, -70.787232 for ~11 minutes. Video focused on both north-bound and south-bound traffic. At 1635, UAS operations were complete.

On April 30th, the UVM UAS Team arrived at 174 State Road Kittery, ME at 1430 to discuss plan of action. UAS operations began hovered over a point at 43.104564, -70.747761 focused on south-bound traffic for ~4 minutes at 1440. At 1500, UAS video focused on beginning of traffic buildup on I-95 south for ~5 minutes. At 1545, the UAS video focused on south-bound traffic hovered over a point at 43.107156, -70.744867 for ~4 minutes. At 1620, UAS operations hovered over a point at 43.100238, -70.753921 focused primarily on south-bound traffic for ~5 minutes. At 1630, UAS operations were complete.

The data processing for this case study involved uploading all of the UAS videos to YouTube.

PRODUCTS

Products for this case study are 10 MP4 video files totaling over 8 GB of data. These videos were uploaded to a YouTube video for accessibility (Figure 34). The UVM UAS team also created support products such as a fact sheet and slide show presentation.



Figure 34. Screen capture of the YouTube video taken during the I-95 traffic monitoring case study.

FRANCONIA NOTCH TRAFFIC MONITORING

SUMMARY

On October 14, 2017, UAS were used to monitor overflow parking area from 1030 to 1430 within Franconia State Park. UVM's UAS team worked with local agencies to acquire footage and photos of the overflow parking situation. UAS were deployed from several areas of interest near popular trailheads during peak foliage season in Franconia State Park. The UAS used for this study was the DJI Phantom 4 which is a quadcopter platform with a high-performance camera that can shoot video in 4K at 30 frames per second. The UAS team had four batteries for the DJI Phantom 4 with each battery capable of a ~25-minute flight. It takes under five minutes to set up the UAS for each flight. The use of UAS for traffic monitoring allows for acquisition of localized spatial information in a timely manner.

METHODS

On October 14th, 2017, the UVM UAS Team arrived at Lafayette Campground Road at 1020 and set up UAS flight signs and traffic cones for safety. At 1030, UAS operations began at Lafayette Campground Road. The UAS took three videos focused on vehicle parking along both north- and south-bound I-93 parking. The UAS also took 15 photos focused on vehicle parking along both north- and south-bound I-93. At 1045, UAS operations at Lafayette Campground Road were completed. At 1215, UAS operations began at the Kancamagus Highway by the Lincoln Woods Trailhead. The UAS took two videos focused on the vehicle parking in that area. The UAS also took nine photos of the overflow parking near this trailhead. At 1245, UAS operations were completed.

The data processing for this case study involved uploading all of the UAS videos to YouTube. This video is restricted on YouTube so only those with the specific URL can view the compiled videos.

PRODUCTS

Products for this case study are 8 MP4 video files totaling over 4 GB of data and 38 JPG photos totaling 188 MB. These photos and videos were uploaded to an [ESRI Story Map](#) for accessibility (Figure 35). Team also created support products such as a fact sheet and slide show presentation.

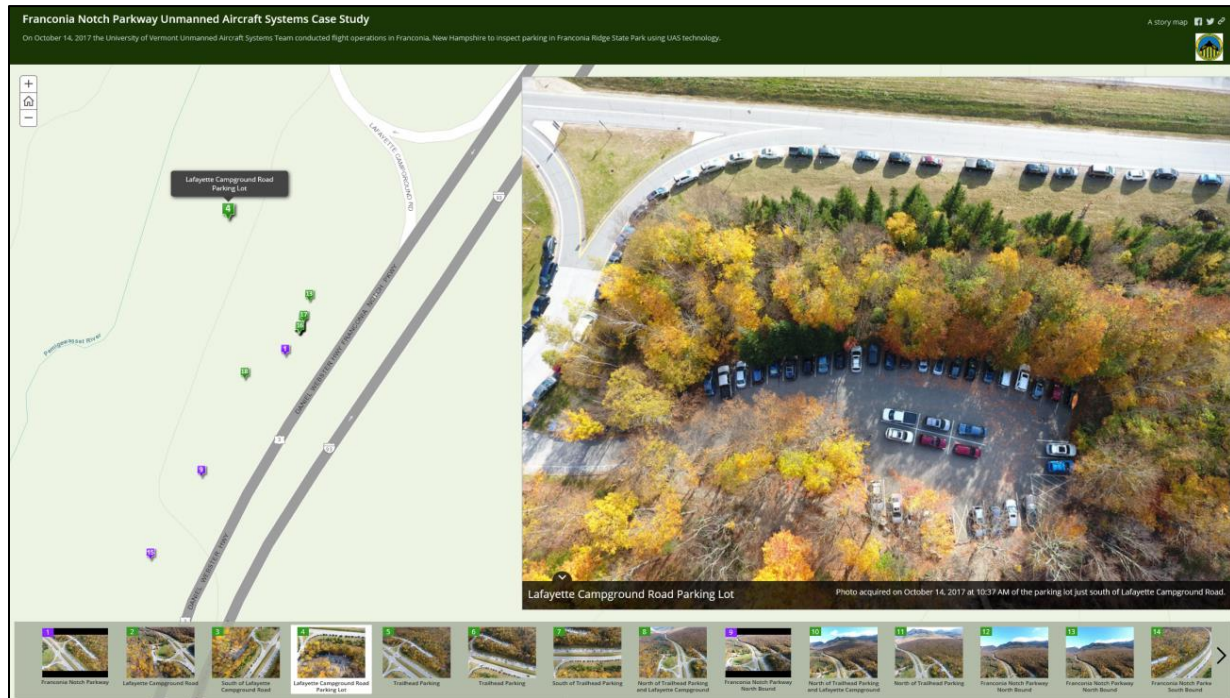


Figure 35. [ESRI Story Map](#) of the Franconia Notch traffic monitoring case study. Each photo and video captured is geotagged and uploaded to an online platform so anyone with internet access can view the data.

TRAFFIC MONITORING STRENGTHS

The use of UAS for traffic monitoring have the capability to acquire accurate data in a timely manner. The DJI Phantom 4 can precisely hover and send live video feeds to the remote control so the pilot has the ability to focus on areas of interest easily. The DJI Phantom 4 also takes little time to set up, where the UAS can be ready to fly in under five minutes. These abilities such quick set up time, acquiring data quickly, hovering that make it easier and safer to fly. The ability to drive onto medians and near highway on ramps allowed the UAS to hover very close to areas without flying directly over cars or people. The UAS team and local agencies worked together to ensure the UAS was acquiring video of the correct area of interest.

The videos were uploaded to YouTube that enables anyone with a web browser to examine the traffic videos. Each photo/video is geotagged so one can acquire location data to evaluate traffic patterns.

TRAFFIC MONITORING LIMITATIONS

In order to acquire video for a larger area, a waiver would be acquired to fly over people, vehicles, and into the natural area. There may be potential public concerns with the use of UAS for this purpose. There are also concerns with UAS causing potential accidents due to distraction.

4.8 CASE STUDY: RAIL & BRIDGE INSPECTION

SUMMARY

On June 1, 2017, Unmanned Aerial Systems (UAS) were used to map a rail line and inspect a railroad bridge. The rail line was mapped to assess the conditions of a two-mile stretch of the New Hampshire central railroad in Lancaster, New Hampshire. Within the rail corridor, a bridge in regular service was also inspected using UAS technologies. UVM's UAS team worked with the NH DOT Bureau of Rail and Transit to acquire data of the rail corridor and bridge. UAS flight operations were carried out by two teams concurrently. Team 1 collected imagery of the entire rail corridor while Team 2 focused on inspecting the bridge that falls within the rail corridor. Two UAS were used for this study: the senseFly Albris and the senseFly eBee Plus. The UAS used for collecting imagery of the rail corridor was the senseFly eBee Plus, a fixed wing platform. The senseFly Albris, a multi-rotor inspection UAS, to capture high-resolution inspection photos of the bridge. The senseFly Albris can acquire perspective views and can fly in hard to reach areas to allow for easy, remote inspection of structures with difficult access, but not near trees or overhanging wires. Weather conditions that day were in the low 70s and low winds.

METHODS

Flight operations were carried out by two teams. Team 1 was responsible for collecting imagery of the entire rail corridor using the senseFly eBee Plus. Operations were carried out from two locations in order for the remote pilots to maintain line of sight of the UAS. The first location was a privately-owned field and the second was an electric substation, both locations were used after proper permission was granted (Figure 36). The senseFly eBee Plus was able to cover the entire area of interest in four flights over the course of 102 minutes of flight time.



Figure 36. The UAS Team performing flight operations for the senseFly eBee Plus

Team 2 focused on inspecting the bridge that falls within the rail corridor. To accomplish this task, the senseFly Albris quadcopter system was used, which has the ability to hover above and below the bridge in manual flight mode. While using its rotating camera that captures high-resolution images, inspectors had the ability to see a live

video feed as well as save photos for further inspection later on. The senseFly Albris was deployed six times to acquire the necessary data. This data was collected over the course of 67 minutes of flight time.

Data processing involved taking the 1,089 images captured by the senseFly eBee Plus and 224 images from the senseFly Albris to generate 2D and 3D geospatial products using digital photogrammetric techniques. The initial processing, which was carried out immediately after flight operations using the eMotion software, synchronizes the images with the flight log on the UAS. The geospatial products were generated using Pix4D. Pix4D first computed a 3D model of the area using the imagery, then used that 3D model to generate a seamless orthorectified image mosaic. A report was also created that provided information on the calibration, geolocation, and point cloud densification details.

The processing for this case study took approximately six hours to complete. Once completed the total file size of the output products was 50GB. The processing was run on a computer with 28-core CPU and 128GB of RAM.

PRODUCTS

Geospatial products included orthomosaic imagery, digital surface model, digital elevation model, and 3D point cloud (Figure 37). High-resolution inspection photos of priority areas are also a product for this case study (Figure 38). The UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 39).

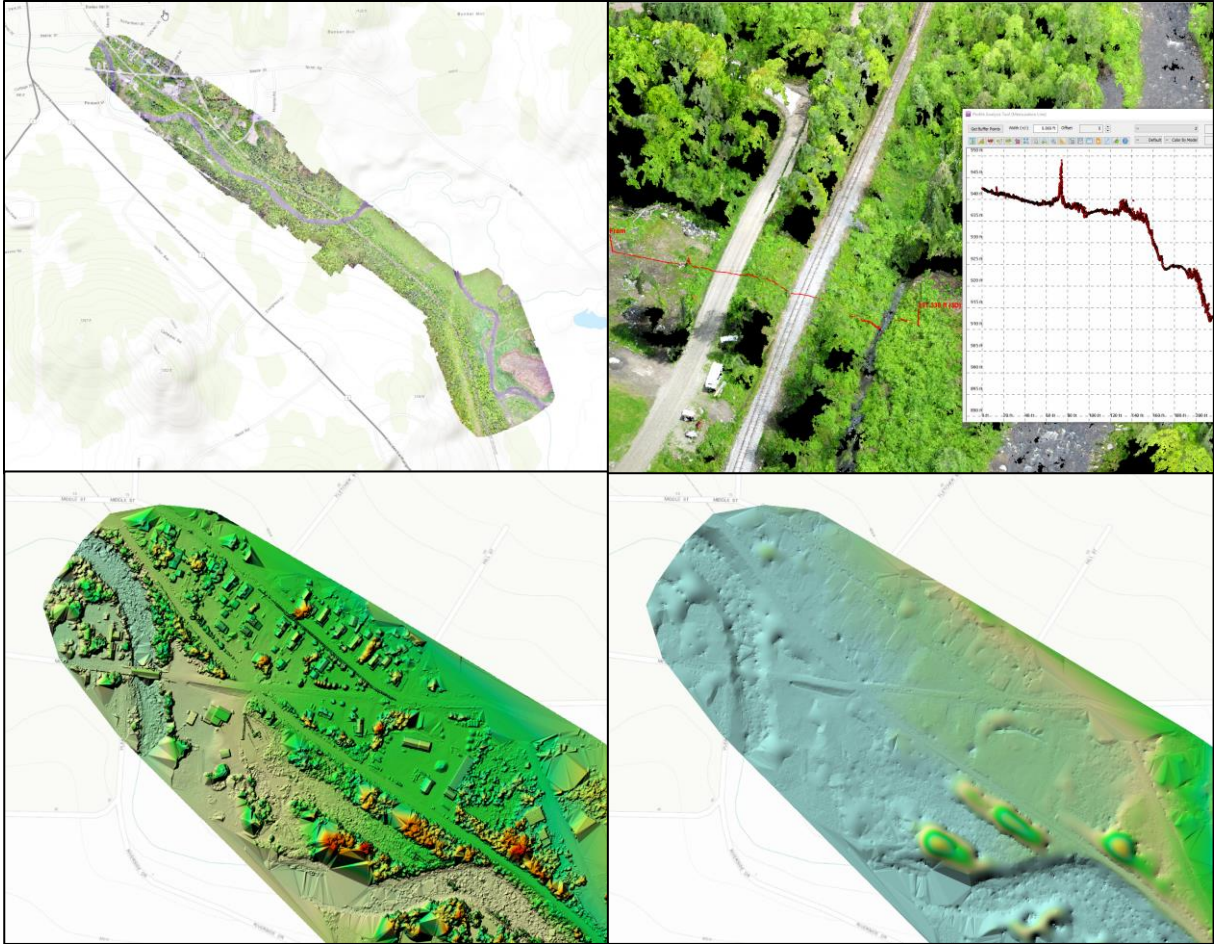


Figure 37. Geospatial products of the rail mapping and bridge inspection case study. Upper left is the orthomosaic, upper right is the 3D point cloud, lower left is the digital surface model, and the lower right is the digital elevation model.



Figure 38. High-resolution inspection photos captured during this case study. The senseFly Albris UAS is able to collect true color photos and videos in addition to thermal images.



Figure 39. Screen capture of the rail mapping and bridge inspection case study [ESRI Story Map](#).

STRENGTHS

The Minnesota Department of Transportation conducted a cost comparison based on the inspection of Duluth's Blatnik Bridge. During a typical bridge inspection, this bridge would require four inspection vehicles, an 80 foot man-lift, and require eight inspection days. To perform this bridge inspection using traditional methods would total to about \$59,000. The cost of using UAS to inspect the same bridge would cost \$20,000 with only 5 days onsite. That is nearly a \$40,000 cost difference between the two approaches. Bridge inspections done with UAS can be performed without closing down traffic on the bridge (Wells). Unfortunately, this case study determined that UAS does not provide cost savings in the inspection.

UAS provides the general overview of the line or bridge to look at damage, accidents, encroachments, flooding when it is difficult to get personnel close to the area of interest.

UAS provides a unique perspective as the UAS can move its camera in almost any direction needed, including the under sides of bridges. The use of platforms with thermal sensors provide an efficient way to detect concrete failure (Wells). Using photogrammetry software like Pix4D, 3D models can be created to determine measurements and large-scale planning.

LIMITATIONS

UAS cannot be used to independently inspect a bridge, but can be used as a tool for bridge inspectors to view difficult to reach areas in certain situations. Measurements can be obtained from UAS data, but hands on inspection like cleaning and testing cannot be replaced by UAS (Wells). UAS is unable to go into the confines of the truss-open deck style bridges.

Inspections in the Hy-Rail vehicle generally cover 10-15 miles per hour, but the UAS covered only 1 mile in approximately 2.5 hours. Bridge inspectors can climb on the bridge and inspect all the connections and bridge members. UAS inspections end up costing more in field work, analysis, and reporting writing as their current operations are more automated. UAS operations also use a significant amount of computer storage without providing the detailed information bridge inspectors need. In NH DOTs experience on state-owned bridges, UAS limitations outweigh the benefits.

4.9 CASE STUDY: ROCK SLOPE

SUMMARY

On July 26, 2017, UAS were used to map and inspect the rock slope and surrounding area. UVM's UAS team worked with local agencies to acquire photos and the data necessary to create a georeferenced point cloud of the rock slope. There were two major objectives for this case study. The first was to create a high-resolution georeferenced point cloud of a rock slope suitable for 3D modeling and visualization to analyze the rock structure. The second objective was to capture high-resolution inspection photos of the rock slope to provide ample viewpoints of the rock face. UAS were deployed from several areas of interest near the rock slope to acquire the necessary data. The UAS used for this study was the DJI Phantom 4 which is a quadcopter platform with a high-performance camera that can shoot video in 4K at 30 frames per second. The UAS team had four batteries for the DJI Phantom with each battery capable of a ~25-minute flight. It takes under five minutes to set up the UAS for each flight. Weather conditions were in the mid-70s on the day of flight operations.

METHODS

The UVM UAS Team arrived to the rock slope by Crawford Notch State Park on the morning of July 26, 2017. The UVM UAS Team set up flight operations at various locations over the rock face. In three flights with the DJI Phantom 4, 310 photos were captured with a total flight time of 30 minutes and 25 seconds.

Data processing involved taking the 310 images captured by the DJI Phantom 4 UAS to generate 3D geospatial products using digital photogrammetric techniques. The initial processing, which was carried out immediately after flight operations using the eMotion software, synchronizes the images with the flight log on the UAS. The geospatial products were generated using Pix4D. Pix4D first computed a 3D model of the area using the imagery, then used that 3D model to generate a seamless orthorectified image mosaic. A report was also created that provided information on the calibration, geolocation, and point cloud densification details.

The processing for this case study took approximately one hour and nine minutes to complete. Once completed the total file size of the output products was 3.3 GB. The processing was run on a computer with a 28-core CPU and 128GB of RAM.

PRODUCTS

Products included 3D point cloud and high-resolution inspection photos (Figure 40 and Figure 41). The [3D point cloud](#) was uploaded to Sketchfab, an online platform, for accessibility. The UVM UAS Team also created support products such as a fact sheet, slide show presentation, and [ESRI Story Map](#) (Figure 42).



Figure 40. The 3D point cloud produced during this case study. This data was also uploaded to Sketchfab.



Figure 41. High-resolution inspection photos captured during this case study.



Figure 42. Screen capture of the rock slope case study [ESRI Story Map](#).

STRENGTHS

UAS provide a unique view of the rock slope that an inspector would otherwise be unable to view from the ground. Manual measurements of rock slopes are potentially dangerous work when using the rope-access method. Without the use of rope-access method, personnel on the ground are limited to only seeing what they can from the ground. Working on the ground by rock slopes exposes the individual to potential rock fall and often high-speed traffic on the adjacent road way. While manned aircraft cannot get close enough to collect the necessary details about the site, UAS are able to get close to the rock face. Using UAS to acquire this data keeps personnel away from the potentially dangerous rock slopes. The highly detailed 3D model created of the rock slope can be used to make measurements in locations that are unreachable by hand measurements.

LIMITATIONS

With most rock slopes being by road ways, it is necessary to close down part of the road to ensure cars are not driving under drone operations. A waiver would need to be acquired to fly over cars and people, but only if the road could not be shut down. Although using UAS is safer in some ways, in this case study the UVM UAS Team was exposed to moving vehicles on then open traffic lane.

Although data obtained during this case study can be uploaded to online platforms, to make measurements on the data one would need access to software programs like Quick Terrain Modeler.

CHAPTER 5: CONCLUSIONS

5.1 OPPORTUNITIES

UAS technology will provide NH DOT the opportunity to revolutionize the way in which they collect data for many different types of activities. Acquiring information using UAS proves to be faster than some traditional methods. UAS can even acquire survey grade data faster than if it were done manually. This saves time and in turn saves money. For most UAS applications, they offer an excellent screening tool while other applications are a good inspection tool. UAS can hover to access difficult to reach areas by traditional methods. Using UAS is also safer than manual inspections since personnel are not putting themselves in dangerous areas except in cases where the UAS operator is next to traffic. Data captured by UAS can create geospatial products that can then in turn be used for analysis and readily integrated with other spatial data. It must be noted that UAS were unable to access inside of bridges for these studies, but may be able to do so in the future.

OTHER STATES & UAS

New Hampshire is not the only state exploring UAS according to Asphalt Magazine, 17 state DOTs have studied or used UAS and 16 state DOTs are exploring UAS usage. DOTs that have used UAS technology include Alabama, Connecticut, Delaware, Idaho, Indiana, Kentucky, Maryland, Massachusetts, Minnesota, Michigan, New York, Ohio, Oregon, South Carolina, Tennessee, Vermont, Pennsylvania, Utah, and Washington. DOTs that are exploring UAS include Alaska, Colorado, California, Florida, Georgia, Hawaii, Iowa, Illinois, Kansas, Mississippi, New Hampshire, New Mexico, Nevada, North Dakota, Pennsylvania and West Virginia (Asphalt) (Wojtowicz 2017) (Wood 2017) (Utah DOT).

5.2 IMPLEMENTATION CONSIDERATIONS

IN HOUSE CONSIDERATIONS

HUMAN RESOURCES

The most important part of any UAS program is the people. A variety of skillsets are needed to make a UAS program within NH DOT successful ranging from UAS flight operations to geospatial data processing and visualization. Investments in technology alone cannot overcome shortchanging training.

To conduct flight operations, NH DOT must have UAS pilots that have obtained their Part 107 Remote Pilot license. Part 107 is the FAA regulation that governs the commercial operation of UAS. Acquiring the license consists of passing an aeronautical knowledge test and undergoing a security screening (https://www.faa.gov/uas/getting_started/part_107/). Since earning a remote pilot license is only a knowledge test, NH DOT recommended that to implement platform-specific training. The remote pilot will need this training to successfully fly the UAS platforms that NH DOT decides to employ.

It is worth noting that different UAS platforms require different levels of expertise. For example, the DJI Phantom 4 that was used for a handful of case studies is fairly easy to fly and this UAS platform would require minimal training. On the other hand, the senseFly eBee Plus flies autonomously, but it requires more technical skills since the pilot has to be familiar with the flight planning program the senseFly eBee Plus uses and enter specific parameters to capture high-quality results. If NH DOT decides to employ UAS in house for the purpose of an eye in

the sky or some inspections to acquire photos and videos than the DJI Phantom 4 would be a great UAS for NH DOT to purchase at minimal cost and would require the minimal new skillsets.

If NH DOT were to employ UAS for survey work or geospatial data then additional skillsets are required outside of piloting the UAS. The senseFly eBee Plus and others are made specifically to map areas so some background in GIS is required to create high-quality results. In addition to entering the specific parameters into the flight planning software, expertise is necessary to process the raw data from the UAS to create geospatial products. After geospatial products are created, then the data can be brought into GIS software to analyze, modify, or extract features.

NH DOT could also hire consultants to assist with UAS projects or training.

UAS PLATFORMS & SENSORS

UAS platforms ease of use and integration vary between systems where some platforms are fairly easy to use, and others require specialized technical skills. UAS platforms that will be easier for NH DOT to integrate will be quadcopters with a camera and gimbal included. These UAS require minimal training to pilot and do not require NH DOT to invest in specialized software and hardware to process and view the data. These UAS can capture photos and videos so they are useful for tasks where aerial media is necessary. Although this platform is best for aerial photos and videos, geospatial products can be produced (accuracy and resolution will be lower). For tasks that do not require survey grade data then this platform can be used to create geospatial products like the rock slope survey.

UAS platforms that may be more difficult for NH DOT to integrate include senseFly fixed wing UAS like the eBee, eBee RTK, and eBee Plus due to the technical skills involved when flying the UAS and processing the data to create geospatial products. Although the fixed wing senseFly UAS platforms are easier to fly in the field because they fly autonomously, they require technical skills to understand how to create high quality maps. Not only does one need the expertise to fly the UAS, but also to process and analyze the UAS geospatial data when using this platform. Another limitation of this is the size of the data products that is produced from processing the data to create geospatial products. The UAS missions that benefit by using this platform are missions where accurate, survey grade data is necessary.

LIABILITIES/INSURANCE

NH DOT will need to consult with the state attorney general's office on specifics regarding liability and insurance. All contractors should be properly insured for any work they do. At the time of this report's publications there is no UAS insurance standard. Some insurance companies do cover UAS operations as part of their general liability coverage while others require a separate policy, sometimes with an external entity.

PRIVACY ISSUES

As privacy issues are one of the most cited concerns in UAS operations, particular attention was paid to public perception during UAS operations of the case studies. At times, it may be necessary to conduct launch and landing of the UAS during flight operations on private land due to UAS platform limitations, terrain, or other factors. When this is the case, landowner approval is required. Being proactive by discussing the UAS operations with landowners in the area to be an effective approach. People are inherently curious and when they have a chance to view the operations up close many of their preconceived notions of UAS may change.

For privacy and harassment laws for New Hampshire, refer to applicable New Hampshire Revised Statutes Annotated 600 laws, including but not limited to:

- RSA 644:2 Disorderly Conduct;
- RSA 644:4 Harassment;
- RSA 644:6 Loitering or Prowling; and
- RSA 644:9 Violation of Privacy

PROJECT COMPLEXITY

UAS missions that will be easier for NH DOT to implement include areas of projects that only capture photos, videos, or virtual reality products as these products do not require specialized software or hardware to process. The case studies that only capture photo or video products were flown using the DJI Phantom 4 quadcopter that is a fairly easy to learn to fly. Projects that will be more difficult to implement are the studies that involved processing the geo-located images to create geospatial products. Such projects require specialized software to process the data and to view and analyze the resulting geospatial products. The specialized hardware and software contribute to both cost and complexity. Although a majority of case studies involved generating geospatial products, there are areas in every case study that may benefit from only acquiring aerial photos/videos if NH DOT decides not to invest in the resources to produce geospatial products in house. Using UAS as a means to acquire aerial perspective may still be beneficial.

The traffic monitoring projects may be the easiest UAS mission to implement into the existing structures of NH DOT due to the type of data produced and the level of expertise required to perform the tasks in this project. The information collected during this study is accessible to most people as videos and images that can be opened up on almost any computer. The data can also be put up on to an online platform like ESRI Story Maps to view the traffic monitoring data with its GPS location to further analyze the traffic as shown below (Figure 43).

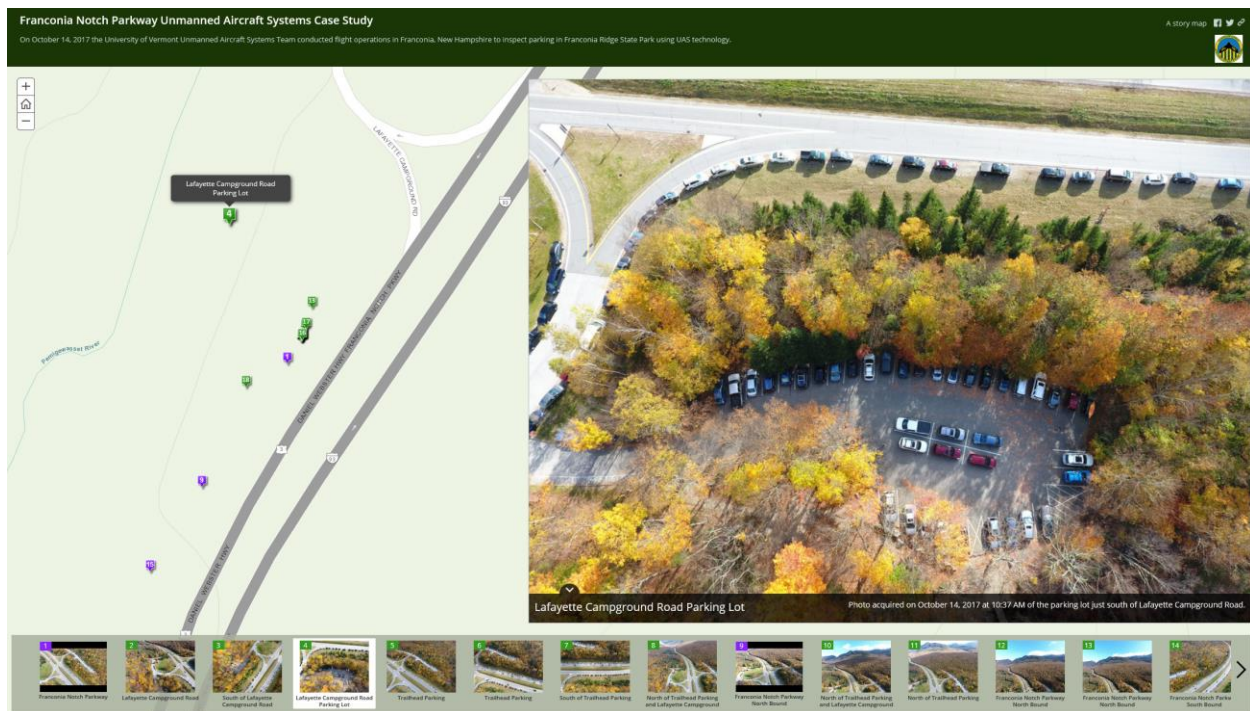


Figure 43. Story Map of the Franconia Notch Traffic Monitoring Case Study. Each photo and video captured is geotagged and loaded to an online platform so anyone with internet access can view the traffic monitoring data. The full Story Map can be viewed with the following link. <http://arcg.is/2xJwBPD>

The accident case study is another UAS Mission that would be easier for NH DOT to implement due to the type of data this study produced, the level of expertise required to complete certain tasks, and the time benefit vs conventional means. This case study would be easier to implement using a quadcopter to gather photos and videos and creating virtual reality products like Hangar 360 (<https://hangar.com/hangar360/>) (Figure 44). Producing these data products does not require any specialized software as the Hangar 360 is processed online.



Figure 44. Virtual reality of the Accident Case Study. The virtual reality can be viewed with the following link.
<https://viewer.hangar.com/360?assetId=/vjxbZVP0>

Using UAS as an assessing tool for bridge inspections may also be an easier project to implement, particularly if the end product was only photos. It should be noted that inspections that involve capturing imagery of the underside of structures require more advanced UAS platforms with gimbal camera along with an operator that has experience in carrying out this type of work.

The aeronautics, construction, dam, and rail mapping would be the most challenging case studies for NH DOT to implement due to the software and hardware necessary to capture, process, and analyze the data. Not only would NH DOT need to invest in the necessary software to process and analyze the geospatial data, but NH DOT may need to invest in specialized UAS platforms. The long-term benefits in safety, cost, and quality are clear, but having the capabilities to carry out such projects would require significant short-term investments.

IT/GIS CONSIDERATIONS

HARDWARE & SOFTWARE

The hardware and software requirements needed to view, process, and analyze UAS datasets differ for UAS data collected for geospatial products and UAS data collected for inspection photos or aerial media. UAS data collected for geospatial products require specialized software programs to process the UAS data that also necessitate specific hardware requirements. For UAS data that is not being processed for geospatial products, they do not have specific requirements for hardware and software so long that the computer can open photo and video files.

Generating the geospatial products can be carried out using Pix4D, a state-of-the-art digital photogrammetric software package. Pix4D first generates a 3D model of the area of interest, then uses that 3D model to generate a seamless orthorectified image mosaic. A report is also created that provides information on the calibration, geolocation, and point cloud densification details. In order for Pix4D to work efficiently, the program has minimum and recommended software and hardware requirements that can be found on Pix4D's website

(<https://pix4d.com/>). The minimum requirements as of 2018 to process UAS data for geospatial products includes Windows 7, 8, or 10, Server 2008 or 2012, 64 bits, any CPU, and any GPU that is compatible with OpenGL 3.2.

After the geospatial products are processed, the data products can be viewed and analyzed on GIS platforms. The orthomosaic and digital surface model can be opened in ArcGIS, MapInfo, ENVI, ERDAS Imagine, and other GIS platforms. 3D Point Clouds can be viewed on platforms like Quick Terrain Modeler (<https://appliedimagery.com/>).

Below is a graphic describing the many general IT considerations NH DOT will need to consider before implementing geospatial UAS work in house (Figure 45).



Figure 45. Graphic describing the IT considerations NH DOT must make before implementing geospatial UAS work.

DATA STORAGE/FORMAT

When processing the UAS data in Pix4D, the user can choose the file formats they want the output data to be saved to. The typical file formats used in Pix4D outputs are TIFF for the imagery, digital surface models, and digital terrain models and LAZ for the 3D point cloud model. The Pix4D website describes the different file formats the data can be saved to with the software it can be opened with, and intended use (<https://support.pix4d.com/hc/en-us/articles/202558499>). Below are tables describing the typical file formats created during the Pix4D process along with the software that can open the data, use, and if the data can be uploaded to an online platform. The UVM UAS Team does not endorse any of the software described below. The Pix4D software updates frequently so the data types for UAS products may change as well.

Table 1. Below describes the typical file format, software, use, and ability to upload to an online platform for densified point clouds.

File Format	Software	Use	Upload Online
.las & .laz	Quick Terrain Modeler	Visualization	No
	Global Mapper ArcGIS	Visualization	
	VRMesh	Visualization Point cloud classification	
	LAStools	Point Cloud Processing	

Table 2. Below describes the typical file format, software, use, and ability to upload to an online platform for raster digital surface models.

File Format	Software	Use	Upload Online
.tif (GeoTIFF)	Global Mapper ArcGIS Quick Terrain Modeler Quantum GIS	<ul style="list-style-type: none"> • Contour lines generation • Distance, area and volume measurements • Comparing volumes between two DSMs • 3D digitization 	<ul style="list-style-type: none"> • ArcGIS Online • ESRI Story Maps

Table 3. Below describes the typical file format, software, use, and ability to upload to an online platform for raster terrain models.

File Format	Software	Use	Upload Online
.tif (GeoTIFF)	Global Mapper ArcGIS Quick Terrain Modeler Quantum GIS	<ul style="list-style-type: none"> • Distance and area measurements • 2D digitization 	<ul style="list-style-type: none"> • ArcGIS Online • ESRI Story Maps

Table 4. Below describes the typical file format, software, use, and ability to upload to an online platform orthomosaic.

File Format	Software	Use	Upload Online
.tif (GeoTIFF)	Global Mapper ArcGIS Quantum GIS AutoCAD	<ul style="list-style-type: none"> • Distance and area measurements • 2D digitization 	<ul style="list-style-type: none"> • ArcGIS Online • ESRI Story Maps

Table 5. Below describes the typical file format, software, use, and ability to upload to an online platform for 3D textured mesh.

File Format	Software	Use	Upload Online
.obj	MeshLab	Visualization	SketchFab
	Global Mapper		
	ArcGIS		
	Rhino		
	3DBuilder		
	Autodesk Maya		
.ply	MeshLab	Visualization	No
	SketchFab	Web viewing and sharing	SketchFab
	Blender, Meshmixer	3D Printing	No

UAS geospatial datasets are often very large so it is important that NH DOT has the storage capabilities in place to store UAS datasets. As an example, the University of Vermont Spatial Analysis Lab has 150 TB of dedicated high-performance network storage that is backed up daily.

DATA INTEGRATION/ACCESSIBILITY

Geospatial data products can be opened in GIS software platforms to view and analyze the data, but most data products produced from UAS can also be uploaded to an online platform like ArcGIS Online. By putting UAS data onto an online platforms it makes the information more accessible to users. Orthomosaics, Digital Surface Models, and Digital Terrain Models can be put on ArcGIS Online. An example of UAS imagery uploaded to ArcGIS Online can be viewed with the following link (<http://go.uvm.edu/acjut>). 3D Point Clouds can be put onto online platforms like SketchFab to visualize 3D data. An example of 3D models uploaded to SketchFab that can be viewed with the following link (<https://skfb.ly/6vqqy>). Virtual reality products like Hangars360 can be easily created and shared. These products provide a 360 degree aerial view of an area and can provide an overview visualization of an area when geospatial UAS products are not necessary. An example of a Hangar360 can be viewed with the following link (<http://go.uvm.edu/vehfo>).

ESRI Story Maps are another way to make UAS datasets accessible to the public and to showcase the data to tell a story. An example of an ESRI Story Map can be viewed with the following link ([ESRI Story Map Link](#)).

5.3 RECOMMENDATIONS

IMPLEMENTATION RECOMMENDATIONS

It is worth noting that the investment of using UAS in house is a huge monetary investment that NH DOT must be prepared to make to use UAS successfully. Not only does NH DOT need to invest in multiple UAS platforms and sensors, but NH DOT must ensure they have the IT/GIS back bone to support UAS implementation. This includes training personnel to fly, process, and analyze the data and also the necessary storage space to store the data products. This investment in UAS implementation is close to \$500,000 to start a successful in-house UAS program.

NH DOT may need to implement different areas of UAS over time as some aspects of UAS are easier to adopt than others. NH DOT has the capabilities now to implement UAS technologies for aerial perspective through photos and videos, but to implement UAS for geospatial data and analysis it will require investments not only in hardware and software, but also trained personnel. UVM UAS Team recommends that NH DOT approach the implementation of UAS in two phases. The initial phase would be to implement simple UAS platforms that require minimal or no additional processing or software to process and view the data. This would allow NH DOT to begin using UAS in-house without investing in the resources necessary to perform advanced UAS processing and analysis. This phase would be to use UAS for aerial perspective through photos, videos, and even virtual reality. Although geospatial products are not produced at this stage, most of the case studies can still benefit from just having an aerial perspective. The UAS missions that may benefit the most at this stage include traffic monitoring, inspection photos, accident reconstruction, construction monitoring, and rock slope study. This stage can also be an opportunity for NH DOT to begin training on the basic processing and viewing of UAS geospatial data. NH DOT can begin basic processing through Pix4D Cloud (<https://cloud.pix4d.com/login>) which will process the individual UAS photos in an online platform and automatically create a web map to view the data. Another option to create basic geospatial products is using Live Map through Drone Deploy (<https://blog.dronedeploy.com/introducing-live-map-make-real-time-drone-maps-with-your-iphone-or-ipad-27752b3963a4>). Live Map is a new tool that will process the data on the fly while the UAS is still in flight which allows for immediate viewing of the imagery results. The benefits to processing the data on the cloud allows NH DOT to practice the skills necessary to capture and process high quality data without the investment of expensive equipment. These beginner yet useful tools for processing data will allow NH DOT to learn the necessary skills to create high quality and meaningful results.

While NH DOT is in Phase 1 of UAS implementation, it is recommended that NH DOT also contracts with UAS professionals for more advanced UAS projects that may require additional processing or analyzing of the data. This will not only provide NH DOT with the information they need, but it will also allow NH DOT to learn more about the advanced UAS work flow required to process and analyze the data. In the following section, details on what NH DOT should ask for in an RFP for advanced UAS products and analysis is described.

Phase 2 of UAS implementation will involve an organizational shift within NH DOT to adopt the use of geospatial UAS data. Not only will this involve investing in specialized mapping UAS and processing software, but it will also include the necessary investments in geospatial software, data storage, and trained GIS professionals. The biggest challenges that NH DOT will face when implementing geospatial UAS data are the size of the data products and training personnel to process and analyze the UAS data within NH DOT. NH DOT must be adequately prepared for these major challenges before implementing Phase 2 into the NH DOT workflow. Although the hardware and software are important in implementing UAS operations, trained personnel may be the most important factor when implementing UAS programs so the data can be used to create meaningful results for NH DOT and the public.

Another, less intensive option may be to hire UAS consultants. This would mean NH DOT does not need to train personnel for UAS field work, but NH DOT must still be prepared to use and store geospatial datasets.

DECISION MAKING

Before contracting UAS work for geospatial products, it is important that NH DOT understands when the use of UAS is advantageous versus manual methods or if a hybrid approach is appropriate. This decision will be based on the specific goals, products, intended use, and support needed for a project. For the most part, UAS will be the most cost effective way to acquire data, but if NH DOT doesn't know what to do with the data then this will result in additional costs and time. NH DOT must examine the limitations and capabilities within the NH DOT IT/GIS frame

work to determine if the use of UAS is beneficial. NH DOT may want to consult with IT/GIS to determine if the work necessary for a project can be done within NH DOT or if the work exceeds NH DOT abilities. In the case where the contractor does all work related to UAS including analyzing the data, then this may also increase costs for NH DOT to contract UAS work.

RFP GUIDELINES

The Request for Proposal (RFP) guidelines described below are specific to geospatial UAS projects that NH DOT cannot do in house during Phase 1 of UAS implementation. As NH DOT moves towards Phase 2 of UAS implementation then the RFP guidelines may need to be updated to reflect NH DOT's ability to perform areas of the UAS workflow. NH DOT should include individuals familiar with UAS operations and data products when evaluating proposals. Before a RFP is released, it is important for NH DOT to have internal discussions about the intended use and goals relating to UAS operations to ensure NH DOT is requesting the correct information in the RFP.

Table 6. Checklist describing the necessary items for NH DOT to ask for in a RFP for geospatial UAS contact. This checklist is a general checklist when contracting UAS work and NH DOT may need to add or change items based on the specific work NH DOT is contracting.

Item	x
Scope of Work. Scope of work will encompass the contractor data acquisition, data processing, and final product development.	
Area of Interest. The area of interest (AOI) should be defined and have a spatial component. The spatial AOI allows for others to overlay the AOI with other datasets to better plan for UAS mission which ensures that the contractor is acquiring the correct data.	
End Use of Data. Define what the end use of the data is. Is the data for an inspection of a bridge? Or for mapping a construction area? The UAS workflow and products differ for almost every use case.	
UAS Platform. The consultant may decide what UAS platform is best suited for the project, but this is where NH DOT may define any platforms that may be required. For example, if this is a RFP for accident mapping, then NH DOT may request that the UAS platform is water proof as accidents often happen during foul weather.	
UAS Sensor. NH DOT should specify the kind of information the UAS needs to acquire. A UAS that only captures photos or videos is going to be different from a UAS that acquires multispectral or thermal data.	
Accuracy. NH DOT should specify the required accuracy necessary to complete the project. Does NH DOT need survey grade data? If so, an accuracy assessment of the data is necessary that would include the consultant to be responsible for the ground survey work to ensure the collected data is survey grade.	
File Formats. NH DOT needs to specify the file format for deliverables to ensure that the formats work for the software at NH DOT. NH DOT may need to have all data products uploaded to online platforms during Phase 1 of UAS integration.	
Products. The end use of data will help inform the necessary UAS products. For example, a traffic monitoring project will only have photo and video products while a mapping UAS project would include imagery, point clouds, and surface models. Although the mapping project produces a handful of products, NH DOT may only need one or two.	
Deliverables. The deliverables need to be defined as the contractor needs to know what data NH DOT is interested in. The deliverables may be the imagery and elevation products or NH DOT may just be interested in data derived from the UAS information like the volume calculations. The deliverables will	

depend on the end use of data and NH DOT IT/GIS capabilities. Deliverables may also include uploading the data to an online web map. NH DOT may also want to request all the raw data.	
Task Schedule. Schedule is developed for each individual project.	
Support. Does NH DOT expect any support with the data after data acquisition and processing?	
References. NH DOT should request applicants provide references of projects that have used UAS for geospatial mapping products and analysis. This will provide information on consultants experience using UAS for mapping.	

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DEFINITIONS

<i>Term</i>	<i>Definition</i>
<i>UAS</i>	Unmanned Aircraft System
<i>UAS Platform</i>	Object that is physically flying
<i>Geospatial Data</i>	Data associated with a location.
<i>Photogrammetry</i>	Use of photography in surveying and mapping to measure distance.
<i>Orthorectified Imagery</i>	Aerial imagery that has been geometrically corrected.
<i>Ortho Mosaic Imagery</i>	Also known as Orthorectified Imagery.
<i>3 Dimensional Point Cloud</i>	A set of data points that have x, y, and z coordinates.
<i>Digital Surface Model</i>	3D representation of the terrain's surface that includes objects like trees and buildings.
<i>Digital Elevation Model</i>	3D representation of the terrain's surface without any objects like trees and buildings.
<i>Part 107 Remote Pilot License</i>	To fly any UAS for commercial use the pilot needs to have their Part 107 Remote Pilot License that can be obtained through a knowledge test and background check.
<i>Pix4D</i>	Pix4D is a photogrammetry software that uses images to create orthomosaics, point clouds, and models.
<i>ArcGIS</i>	ArcGIS is a software for the visualization and analysis of geospatial data.
<i>ENVI</i>	ENVI is an image analysis software.
<i>ERDAS Imagine</i>	ERDAS Imagine is a software specifically for raster data sets.
<i>MapInfo</i>	MapInfo is a software for the visualization and analysis of geospatial data.
<i>Quick Terrain Modeler</i>	Quick Terrain Modeler is a 3D point cloud and terrain visualization software package.
<i>ArcGIS Online</i>	ArcGIS Online is an online platform for visualization and some basic analysis of geospatial data.
<i>SketchFab</i>	SketchFab is an online platform to publish and share 3D models.
<i>Hangar 360</i>	Hangar360 is a free app for DJI drones to easily create and share 360 degree photos.
<i>ESRI Story Map</i>	An online platform that combines maps, narrative text, images, and multimedia content